G. Water Quality

Water Quality

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Introduction

The quality and quantity of water in forest streams and lakes, wetlands, and nearshore marine/estuarine waters is a fundamental property important to their use as habitat for aquatic ecosystems, water supplies and recreation. Land use activities, including forest management, can affect important water quality conditions, such as temperature, clarity, and concentrations of organic and inorganic substances.

Water quality can be impacted by forest practices in a variety of ways. Sediment concentrations can increase due to accelerated erosion (Swanson et al., 1987); water temperatures can increase due to removal of overstory riparian shade (Brown, 1969; Sullivan et al., 1990; Adams and Sullivan, 1990); slash and other organic debris can accumulate in waterbodies, depleting dissolved oxygen, and altering water pH (Plamondon et al., 1982); wetlands may be directly altered or created by physical modification resulting from culvert installation and placement of fill material (Binkley and Brown, 1993; Richardson, 1994; Shepard, 1994). Dissolved oxygen, nutrients and pH can have direct and indirect effects on stream water chemistry and aquatic ecosystems, but problems with these parameters are not commonly associated with well-managed forest practices. The degree of change in water quality that may result from forest practices depends on a number of factors including the water quality parameter, the type of waterbody, the physical and vegetative condition of the watershed, the type and location of land use, the design and application of forest practices, the intensity of site disturbance, and climatic conditions (Rice and Datzmann, 1987; Riekerk et al., 1989). Although not typically associated with forest practices, water withdrawals may adversely impact water quality in forested areas and heighten water quality sensitivity.

State water quality standards specify chemical and physical water quality parameters of importance as turbidity, water temperature, dissolved oxygen, and pH. Federal water quality standards also provide standards for nitrogen concentration with regards to drinking water supplies. The purpose of the water quality module is to determine whether these and other parameters within waterbodies found in the WAU are vulnerable to forest practices at the watershed scale. Vulnerability is defined as the reasonable likelihood that state water quality standards may be exceeded by the effects of forest practices. This module also addresses other indicators of water quality that are within the authority of the Forest Practices Board, although they may not necessarily have been adopted as numeric water quality criteria. Biological conditions are not directly assessed in this module.

This assessment will predict the locations of waterbodies occurring in the watershed where numeric water quality criteria, or other criteria as specified in this module, are likely to be exceeded as a result of forest practices. Other land use practices that may also occur in the watershed, such as agriculture, grazing, or urbanization can have equal or greater effects on water quality and quantity. These effects may be identified where important in the interpretation of watershed processes, but they are not the focus of this assessment.

Water quality prediction at the scale required by Watershed Analysis required development of new methods for evaluation. Methods provided in this module are seen as preliminary and the module is expected to be refined with use and with the addition of new methods to address a broader range of water quality characteristics as they evolve. Other modules in Watershed Analysis address the vulnerability of specific beneficial uses such as fish habitat or public works. This module more sharply focuses on water quality and quantity as a mechanism influencing those beneficial uses. There is inevitably overlap between these perspectives, and the water quality analyst is expected to be highly interactive with other analysts throughout the assessment.

Critical Questions

The water quality module collects information to determine whether water quality parameters for waterbodies within the watershed are vulnerable to the cumulative effects of forest practices. The following critical questions address water quality concerns and functionally outline the assessment procedure.

- What waterbodies occur in the watershed and where are they located?
- What is the vulnerability of waterbody parameters to potential changes in input variables?
- What do current water quality conditions or changes from past conditions indicate about the vulnerability of the waterbodies?
- If a waterbody is found to be vulnerable to an input, is there information to identify sources of sediment, nutrients, heat, or organic matter in order to establish sensitivity?

Assumptions

A number of fundamental assumptions underlie the approach developed within this module. The most fundamental assumption is that the analysis use the best available scientific information and techniques in accordance with the expected scope of analysis. The module analysis methods themselves are designed to change as newer, more refined methods are developed. The module provides a framework for the assessment of water quality based on several principle assumptions.

1. The need to address water quality applies to all surface waters of the state.

2. State and federal surface water and drinking water quality standards identify important water quality characteristics.

3. Changes in input variables (e.g., sediment, wood, heat energy, and water quantity and chemistry) to each waterbody can result in changes in water quality and changes in the level of support to beneficial uses.

4. Water quality parameters vary significantly in both short-term time and space. Separating natural variability from land use effects may be possible when evaluating spatial variability. However, a realistic characterization of the frequency and magnitude of water quality conditions through time based on watershed analysis field surveys may not be feasible due to time constraints.

5. Waterbodies differ in their “functional characteristics.” These characteristics determine the beneficial uses of the waterbody and its vulnerability to changes in input variables.

6. A variety of land use activities and natural processes can cause changes in water quality. The presence of land uses other than forest management can have significant effects on water quality that may not be fully characterized in the watershed analysis. The Watershed Analysis methodology may not adequately characterize non-forestry effects on water quality.

7. The current condition of a waterbody represents its response to past and current watershed processes. Current condition and past changes are indicators of the potential of the waterbody to be influenced by watershed processes and land use activities.

Overview of Assessment and Products

The objective of the Water Quality Module is to (1) identify waterbodies within the WAU or waterbodies outside the WAU that may be directly affected by watershed processes within the WAU, and (2) to assess the potential for their characteristics to change with forest management. The analyst establishes the potential response based on watershed characteristics using such tools as topographic and geologic maps and soil surveys. The occurrence of specified features identifies locations where water quality response are reasonably likely to occur if protection is not provided during forest practices.

The first step of the water quality module is to identify and map all of the waterbodies existing in the watershed (Waterbody and Water Supply Identification, Characterization and Mapping). Any waterbodies not already found on the WAU basemap are added and the updated WAU basemap is re-distributed to other module analysts. (In most cases, it will be beneficial for other module analysts to assist in production of the map.) Wetlands identified during aerial photo analysis, field assessment, or interviews with local landowners or tribes, or from map data sources that are not on WAU basemaps should be included. The water quality analyst is expected to identify only larger wetlands with aerial photographs during this assessment. It is assumed that smaller wetlands are identified during site-specific activities according to Forest Practices Wetlands Regulations so there is no expectation that these are to be identified during Watershed Analysis. The public works analyst identifies public works with water quality concerns such as water supplies and fish hatcheries (information is provided on Form H-1 in the Public Works module). These sites are also added to the revised WAU basemap.

Next, waterbodies and their associated water quality parameters are assessed for vulnerability to input variables (Waterbody Vulnerability Assessment). For purposes of Watershed Analysis, vulnerability is defined as the potential for adverse response of the water quality characteristics to changes in input of sediment, heat energy, nutrients, organic matter, or chemicals resulting from forest practices. Vulnerability to change is not based on current water quality condition although the current status is useful in evaluating the validity of vulnerability determinations based strictly on watershed conditions.

Through the adoption of water quality standards, the state of Washington defines the beneficial uses to be protected in each waterbody as well as numeric water quality criteria necessary for specific parameters that help protect these uses. A number of water quality parameters have been adopted as standards by the Department of Ecology. Water quality parameters that may be affected by land use activities (timber harvest, grazing, urbanization, etc.) include numeric values for temperature, turbidity, pH, and dissolved oxygen (DO). Water quality criteria can also be in narrative form, such as general prohibitions against the presence of toxic, radioactive, or deleterious materials in amounts harmful to designated uses, and prohibition on the deterioration of aesthetic values. For the most part, this module uses watershed criteria selected as indicators of adverse change in water quality relative to state water quality and federal drinking water numeric criteria. Habitat vulnerability and sensitivity to coarse and fine sediment loading is determined in the Fish Habitat and Channel modules for streams and wetlands where the dominant beneficial use is fish (WFPB, Watershed Analysis Manual, Appendices E and F, 1993).

The vulnerability of waterbody parameters to input variables is assessed by examining the potential for change from forest practices, using specific physical and biological conditions in the watershed that are likely to trigger changes in input of sediment, energy, organic matter or nutrients that would be sufficient to affect the ability of the waterbody to meet water quality standards. Criteria for identifying watershed situations such as soils, elevation, or flow where adverse change to water quality parameters may occur are provided based on review of the scientific literature and professional knowledge and experience. If specified watershed conditions that can influence a receiving waterbody are found, the water quality parameter is assumed to be vulnerable to the identified input variable for that waterbody, regardless of whether or not it has already been affected.

There are considerable differences among waterbodies and water quality parameters in their response to forest practices (MacDonald et al., 1991). Therefore, the need for analysis, and the likelihood of identifying vulnerability in water quality parameters, differs with each watershed. Table G-1 lists the status of analysis of water quality parameters by waterbody in this module. State water quality standards need to be met, but this module focuses on conditions likely to be affected by forest practices.

The vulnerability assessment for each water quality parameter is guided by a flow chart specifying methods for evaluating each type of waterbody. All watersheds will have streams and most will have wetlands. Many watersheds will not have lakes, water supplies, or estuaries and no assessment steps are required for water quality parameters where they do not exist. The assessment flow chart provided for each parameter guides the analyst to identify watershed conditions and vulnerability by directing them to specific methods of assessment for each.

Conditions and observations of the vulnerability assessment are recorded on the Waterbody Vulnerability Determination Worksheets (Form G-1 and G-2).

Water Quality Vulnerability Maps drawn for each water quality parameter show locations where a moderate or high vulnerability was identified, and the zone of influence if it can be determined. It is assumed that other waterbodies have low vulnerability if not specifically depicted on the maps. Waterbodies and water quality parameters vary significantly in the likelihood of response to land use effects. Some water quality parameters are often vulnerable to changes in input factors due to forest practices (temperature, sediment) and assessment products will always be included in module results and considered for resource sensitivity during the Synthesis stage of Watershed Analysis. Several water quality parameters are only vulnerable in relatively few situations (e.g. nutrient concentration and dissolved oxygen) and these are reported only when specific watershed conditions exist. All water quality parameters may vary naturally in watersheds but some are not significantly influenced by forest practices (pH and fecal coliform). These receive a standard call of low vulnerability to forest practices and are not assessed further during watershed assessment. This is not to infer that these parameters could not be adversely affected by other land use activities within the watershed, nor that naturally occurring conditions may not also influence their status.

The hypothesis of water quality vulnerability may be tested with water quality data when they exist. Usually, the analyst will not directly measure water quality parameters, though data may be available from a variety of sources. Historic information and water quality data may allow the analyst to test hypotheses. The utility of data for evaluating the validity of vulnerability determinations varies depending on the initial call and whether past management has triggered a response. If data demonstrate existing exceedance of water quality criteria, the information can directly affect the vulnerability call if no vulnerability had been identified or could be used to validate the call if moderate or high vulnerability had been hypothesized. The usefulness of data will also be dependent on the data itself—how, where, and why it was collected will influence its value in addressing watershed analysis questions.

Table G-1. Water quality parameters and input variables

		Waterbody Type				Water Supplies	
Water Quality Condition	**Input Variable**	**Streams**	**Lakes**	**Wetlands**	**Nearshore Marine-Estuarine**	**Drinking Water**	**Fish Facilities**
Physical							
Temperature	Heat Energy	1	1	1	4	1	1
Turbidity	Fine Sediment	3	3	3	3	3	3
Accretion	Fine Sediment	5	1	1	6	5	5
	Coarse Sediment	5	1	1	6	5	5
Water Quantity	Low Flow	6	6	6	6	6	6
Chemical							
Nitrogen	Nitrogen	1	1	4	6	6	6
Phosphorus	Fine Sediment	1	1	2	6	4	4
Dissolved Oxygen	Organic Matter	1	1	4	4	1	1
Acidity/ Alkalinity (pH)	Organic Acids/ Inorganic bases	4	4	4	4	4	1
TOC	Organic Matter	4	4	4	4	6	4
Fecal Coliform/	Animal or Human Waste	4	4	4	4	4	4
Cryptosprid-ium/Giardia	Organic and Synthetic Chemicals	2	2	2	2	2	2
Toxic Contaminants	Fertilizer	2	2	4	4	1	1
Biological	Biologic Integrity	3	3	3	3	1	1
	Physical Habitat	5 (fish-bearing)	4	1	4	--	1
		3 (non-fish)	4	1	4	--	--

1 = Routinely assessed in the Water Quality Module.
2 = Usually addressed by Standard Forest Practices. Only assessed by the Water Quality Module if specific conditions exist.
3 = Probably affected by forest practices but not currently addressed in module due to incomplete methods at time of adoption of current version of the WFPB manual.
4 = Unlikely to be significantly affected by forest practices except where criteria specified in manual exist.
5 = Addressed in other modules in WFPB Watershed Analysis Manual
6 = Methods not included in module although recommended that specialists conduct assessment, if needed.

The assessment may be an iterative process that requires repeated evaluation of information and testing of hypotheses. Water quality evaluation and hypothesis development is initially based on existing information. Level 2 or follow-up analyses may try to verify these hypotheses using appropriate monitoring techniques. Opportunities for additional measurements may be seasonally influenced because many water quality parameters are highly variable over the course of a year.

The final step of the water quality module assessment is to produce a report of the findings and notify other module analysts of the vulnerability determinations for each waterbody present in the watershed. These analysts may need to develop additional information that is not normally called for to determine the sensitivity of the waterbody to forest practices during the Synthesis phase of the Watershed Analysis. The water quality analyst will work with the other module teams such as mass wasting, surface erosion, hydrology, stream channel and fish habitat during synthesis to further refine potential secondary or synergistic effects of forest practices and to combine the hazard and risk assessments into the rule call and causal mechanism reports. Prescriptions to address identified water quality sensitivities will be developed by the prescription team.

Qualifications

The water quality assessment depends on qualified individuals to identify waterbodies and interpret their conditions in relation to water quality. This assessment requires expertise in identifying waterbodies, analytical skills in evaluating water quality data, and understanding of the physical and chemical characteristics of the aquatic system. Certain basic skills, training, and experience are necessary to effectively implement the standard water quality assessment module. Most natural resource scientists with the appropriate qualifications should be able to do this module. Given the broad range of parameters evaluated, training should orient the analysts to the scope of the module. The water quality analyst may incorporate other specialists participating in a watershed analysis to help them with the assessment.

A level 2 analysis presupposes a higher level of training and ability to independently develop and implement relevant analysis to address issues and observations not satisfactorily explained by the standard analysis. It would be beneficial for a water quality analyst to exhibit an interdisciplinary background to successfully perform this module. While there are many possible backgrounds that could provide the foundation necessary, the following criteria provide necessary qualifications for those performing the water quality assessment.

Skills

Level 1. Knowledge of the physical, chemical, and biological characteristics of aquatic systems and processes affecting water quality in forested and mountainous terrain. The ability to identify waterbodies with aerial photography is highly desirable, although this skill may be drawn from the watershed assessment team.

An understanding of the primary parameters affecting water quality in the forested environment as reviewed and synthesized in:

> MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA910/9-91-001. USEPA Region 10, Seattle, WA. 166p.

Level 2. In addition to level 1 skills:

- Experience with water quality sampling and monitoring methods and quantitative analysis.
- Experience in detecting physical changes to waterbodies over time (e.g., eutrophication of lakes, roading, diking, or ditching of wetlands.)

Education and Training

Level 1. Bachelor of Science degree in a physical or biological science with significant course work in, but not limited to: water chemistry, water resources, aquatic biology, limnology, forest hydrology, wetland science or ecology, and/or marine science or fisheries.

Level 2. Master of Science degree in physical or biological sciences with a significant amount of course work or other training in, but not limited to: water chemistry, water resources, aquatic biology, limnology, water quality sampling and monitoring, forest hydrology, wetland science or ecology, and/or marine science. Five years of experience and level 1 qualifications may be substituted for an MS.

Experience

Level 1. A minimum of two years of applied experience gaining the abovementioned skills.

Level 2. Experience conducting relevant independent research and/or water quality sampling and monitoring, and a minimum of two years of professional experience.

Background Information

To begin the assessment, several key data sources are necessary including the DNR hydro- layer and wetlands maps, soil maps, and aerial photographs. Once the initial screen of waterbody/parameter conditions is completed, some additional data may be necessary. This section identifies necessary start-up information. Additional data sources are listed within the specific methods for each waterbody.

Maps

- Topographic maps of the watershed (USGS 7.5 minute series required, where available).

- WAU boundary base map overlaid with DNR's hydrography layer at 1:24,000 scale and wetlands delineations.

- National Wetlands Inventory (NWI) maps (7.5 minute series). These maps show wetlands which have previously been identified. NWI maps vary considerably in their relative accuracy and reliability because varying levels of ground verification occurred across regions after aerial photos were initially interpreted. Therefore, it is up to the analyst to determine how to use these maps. NWI maps may soon be available in digital format from DNR GIS (Liz Thompson, 360/902-1224) or hard copy maps from DNR Photo and Map Sales (360/902-1234). Digital wetlands map data is also available over the Internet from US Fish and Wildlife Service (Herman Robinson, 813/893-3624).

- Soil Survey Maps, Soil Descriptions. Existing soil survey information can be obtained from local offices of the National Resource Conservation Service (NRCS), DNR, US Forest Service, and in some cases, local landowners. A limited number of NRCS soil surveys are also becoming available in digital format.

In addition, the water quality analyst should consult with the public works and fish habitat analysts to identify the location of municipal or domestic water supplies and fish hatcheries.

Aerial Photographs

Use the most recent coverage available (1:12,000 scale or better, if available). It is recommended that the analyst also examine past photos, if available.

Information Provided to Water Quality Analyst By Other Modules

General:
- DOE water class designation for WAU.
- Sub-basin designations.

Riparian:
- Potential and existing shade conditions (Riparian Shade Situation Map D-4).

Channel:
- Gradient/confinement of all typed waters (Gradient Map E-1).

Hydrology:
- Flow data from existing stream gages.

WS/PW:
- Information about water quality concerns of public resources and fish facilities.

Water Quality Data and Other Information

- Washington Department of Ecology (DOE)

  - *Section 303(d) List* (DOE, 1996)- A state list of water quality-limited waterbodies (streams, lakes, and estuaries) where State water quality standards are not met and where technology-based controls are not sufficient to achieve water quality standards.

  - Supporting information used to determine listing from appropriate DOE representative.

Other water quality data may be available for the watershed. The analyst is encouraged to proceed with waterbody identification and initial stages of analysis prior to querying for data from the following sources since many will not be relevant if watershed screening criteria are not met. Sources of water quality data, though often variable in their availability, coverage, and usefulness, may include:

- *Local Tribal Ambient Water Quality Data.* Limited ambient water quality data are available from the tribes, existing in various formats for various parameters (e.g., temperature and some water chemistry). Data requests can be made to the Northwest Indian Fisheries Commission (360/438-1180) or directly to local tribes.

- *County Water Quality Data.*

- *Washington Department of Ecology*-Water Quality Monitoring Data. Extensive permit-related and some ambient monitoring data exist for various facilities, locations, and parameters across the State. Information is available from the DOE Water Quality Program at (360)407-6400, or write: WQ DOE, P. O. Box 47600, Olympia, WA 98504-7600.

- *Washington Department of Ecology*—Environmental Investigations Laboratory Services (EILS) has some ambient water quality data dating back to 1959 from some sites located statewide. Current water year from 82 stations is available on web page (http://www.wa.gov/ecology/ecyhome.html) and annual report.

- *United States Geological Survey Miscellaneous Water Quality Data and National Water Quality Assessment (NWQA) data.* This data is published annually for selected stations but varies considerably in the completeness, coverage, and frequency of data collected. It may be acquired from local libraries or by contacting the USGS directly. USGS hydrology data is also available on CD ROM from several suppliers.

- *Washington Water Resources Inventory System (WRIS).* An inventory of fish habitat maintained by the Washington Department of Fisheries and Wildlife.

- *National Pollutant Discharge Elimination System (NPDES) Permit.* On limited occasions there may be a facility within the watershed which has been required to collect specific point discharge and ambient monitoring data under a NPDES Permit which may provide useful information.

- *Drinking Water Utility Records—Annual Report to the Department of Health (DOH), Operational Records, Annual Analysis.* This valuable information should be obtained from any local water purveyors in the watershed.

Assessment Methods

Startup

Unlike other modules, the scope and scale of the water quality assessment may vary from watershed to watershed depending on team decisions regarding the need for water quantity assessment and the allocation of duties among the riparian, fish habitat, and stream channel analysts. Decisions regarding the sharing of tasks and the extent to which water quantity is assessed should be made at the beginning of the watershed analysis process. Undoubtedly, continual interaction among scientific analysts will also be needed. These interactions may be initiated at any time during assessment, although it may be useful for the water quality analyst to develop the waterbodies map beforehand.

The need to include water quantity in the watershed assessment and prescriptions should be scoped by the watershed analysis team at the startup of watershed analysis. Forest practice effects on peak flow are addressed in the hydrology module. The extent to which low flow may affect water quality conditions should be addressed by the water quality analyst working with the hydrology analyst. Although forest practices generally do not reduce summer lowflow, water withdrawals from non-forestry related activities could reduce flow and increase water quality vulnerability to forest management activities. It is not expected that this will be an issue in most watersheds and the need to assess non-forestry related impacts on water flow is determined by the entire Watershed Analysis team based on prior knowledge of impacts.

Scoping is done by the analysts and managers responsible for the watershed. Agencies and others with information are encouraged to bring this information forward as a contribution to scoping. The group considers important linkages between water rights, non-forestry activities, forest practices, and water quality. If there is likelihood of additional vulnerability from forest-related activities, then some analysis of that is expected in the watershed analysis. The team develops a workplan for considering what water quality parameters might be affected and where, the relationship between forestry and non-forestry related activities, and the scope of their work. If analysis of water quantity occurs and a relationship to forestry or non-forestry activities is discovered, a causal mechanism report on water quantity is developed. Ultimately, the appropriate jurisdiction(s) is notified if problems are found.

In addition, there are many tasks that may be potentially shared with other module analysts. Water quality problems may be discovered by the public works or fish habitat analysts. The stream channel analyst may identify streams where sedimentation or other channel disturbance may also impact temperature. The riparian analyst works with shade and evaluates current, and to some extent potential shade. Many of the relationships between public resources and watershed conditions will be identified during the synthesis phase of the analysis. However, consultation among these analysts before and during assessment will greatly facilitate sharing of duties and development of interpretations and products.

Waterbody and Water Supply Identification, Characterization and Mapping

The first step of the water quality assessment is to identify and map all of the waterbodies in the watershed on the DNR hydrography base map. In most cases, this task is best accomplished jointly with fish habitat, public works, stream channel, and hydrology analysts. This map should be labeled Map G-1. Streams and major wetlands occur in virtually all watersheds, while lakes and nearshore marine/estuarine waters are more watershed-specific.

Streams

The WAU basemap developed for the project (see startup products) will have the hydrography of the watershed. Streams, lakes, and some major non-forested wetlands, reservoirs, and marine waters will be depicted on the DNR base map. However, the base map may be missing some large wetlands and public water supplies, as well as small or intermittent streams. To the extent possible, the water quality analyst will attempt to update the stream type map by consulting with local tribes, DNR, and landowners using stream typing criteria adopted by the Forest Practice Board in November 1996. Public water supplies will be identified by the water supply/public works analyst. Hence, mapping of additional waterbodies sensitive to changes in inputs affecting water quality will be limited to locating all readily identifiable wetlands and incorporating information collected by the water supply/ public works analyst.

Wetlands

Wetland Classification

Lakes are commonly defined as waterbodies with water deeper than 6.6 feet (2m), and wetlands are all shallower waterbodies. Wetlands are classified into groups based on similar attributes to facilitate decision-making and further analysis. There are several classifications of wetlands that are used for different administrative or scientific purposes. One of the oldest, and best known is the U.S. Fish and Wildlife Service system used in the National Wetland Inventory (NWI) (Cowardin 1979). The Cowardin system is based on shared characteristics of landscape setting, vegetation and water regime. It was designed to help identify different wetland habitat types.

The Forest Practices Board developed a wetlands classification system for administering forest practices in 1992 (WAC 222-16-035). Criteria for classification of wetlands according to the Forest Practices Board method (WFPB 1993) is provided in Table G-2. The major criteria for grouping under this classification are the size of the wetland, presence or absence of open water, and the type of vegetation present (forested, nonforested, bog or fen).

Table G-2. Definition for Wetland Typing System
Washington Forest Practices Board (1993)

Wetland Class	Wetland Type	Definition
Nonforested Wetlands		Any wetland or portion thereof that has, or if the trees were mature would have, a crown closure of less than 30 percent
	Type A Wetland	Greater than 0.5 acre in size, including any acreage of open water where the water is completely surrounded by the wetland; and associated with at least 0.5 acre of ponded or standing open water. The open water must be present on the site for at least 7 consecutive dates between April 1 and October 1. Bogs and fens greater than 0.25 acres, as well as forested bogs and fens.
	Type B Wetland	Applies to all other nonforested wetlands greater than 0.25 acres.
Forested Wetland	Forested	Any wetland or portion thereof that has, or would have mature trees, and crown closure of 30 percent or more.

The FPB and NWI classifications provide some information that may be useful in establishing the effectiveness of a wetland at trapping sediments because they are partially based on vegetation. Unfortunately, these classifications are not very useful in assessing the probability of sediment retention because they do not contain any criteria based on connections to the stream system. The NWI classification considers streams and rivers as separate wetlands and does not provide any information about the connectivity between a wetland and an adjacent stream, a common condition in forested watersheds. WAC 222 classifies riverine associated wetlands as Type 2 water if they are used by salmonids for off-channel habitat.

A hydrogeomorphic classification of wetlands (HGM) was developed by Brinson (1993a). The HGM approach has been specifically named in the National Action Plan as the vehicle through which regionally specific methods are to be developed (GPO, 1996) and Washington has decided to base its Wetland Function Assessment Project on the national HGM approach (DOE 1996). The HGM wetlands classification method is designed to categorize wetlands by characteristics that strongly influence wetland functions. These include: geomorphic setting, dominant sources of water, and hydrodynamics. Geomorphic setting refers to the landform of a wetland and its topographic position in the landscape. Water source refers to the origin of the water in the wetland, and hydrodynamics refers to the direction of movement and energy level of water in the wetland. Table G-3 displays the hydrogeomorphic classes of wetlands with associated dominant water source and hydrodynamics.

Table G-3. Hydrogeomorphic Classes of Wetlands Showing Associated Dominant Water Source and Hydrodynamics

Hydrogeomorphic Class	Dominant Water	Dominant Hydrodynamics
Riverine	Overbank flow from channel	Unidirectional, Horizontal
Depressional	Return flow from groundwater and inter-flow	Vertical
Slope	Return flow from groundwater	Vertical
Flats	N/A	N/A
Lacustrine Fringe	Overbank flow from lake	Bidirectional, Horizontal
Estuarine Fringe	Overbank flow from estuary	Bidirectional, Horizontal

The water quality module wetlands assessment is based on the HGM approach to naming and determining wetland function. This is because the HGM approach is more consistent with the purpose of watershed analysis to determine the effect of changes in watershed processes on wetland function than the Forest Practice Board classification system, and because analysis will be consistent with evolving agency approaches to be applied on all lands within Washington.

HGM classification is hierarchical. At the highest level, wetlands are grouped into classes based on geomorphic characteristics. Subclasses for each of these Classes are then defined regionally. Table G-4 displays the HGM Classes and Subclasses for Washington proposed by the Washington State Wetland Function Assessment Project (DOE, 1996). Table G-5 summarizes the main characteristics of the subclasses that will be employed in this assessment.

Table G-4. Regional Hydrogeomorphic Classes and Subclasses for Washington State

Class	Subclass
Riverine	Flow-through and impounding
Depressional	Flow-through and closed
Slope	Connected and unconnected
Flats	None
Lacustrine Fringe	None
Estuarine Fringe	Tidal saltwater and tidal freshwater

Table G-5. Definitions of Regional Hydrogeomorphic Subclasses

Regional Subclass	Definition
Riverine **I**mpounding **(RI)**	Retain surface water significantly longer than the duration of a flood event (>1 week)
Riverine **F**low-through **(RF)**	Do not retain surface water significantly longer than the duration of a flood event
Depressional **F**low-through **(DF)**	Depressional wetlands that have a surface water outflow to a stream or river for at least part of the year
Depressional **C**losed **(DC)**	Unconnected depressional wetlands may have surface water inflow but no outflow through a defined channel
Slope **C**onnected **(SC)**	Slope wetlands with a surface water connection, at least periodically, to an intermittent or perennial stream or other surface water body connected to a stream or river
Tidal **S**altwater Fringe **(TS)**	Estuarine fringe wetlands in which the dominant water flow has salinity that is higher than 0.5 parts per thousand
Tidal **F**reshwater Fringe **(TF)**	Estuarine fringe wetlands in which the dominant water flow is tidal but freshwater, with salinity below 0.5 parts per thousand

Identification and Mapping

Using available maps, aerial photography, and field inspection as warranted, the analyst classifies each wetland included in analysis, using both the DNR regulatory categories in Table G-2 and the regional hydrogeomorphic classes and subclasses in Tables G-4 and G-5 based on geomorphic setting, water source, and hydrodynamics. This information is included on the Wetlands

Assessment worksheet (Form G-1). See Appendix section, "Profiles of Wetland Classes and Subclasses for Lowland Washington" (DOE, 1997) for detailed descriptions of HGM categories. The Washington State Wetlands Function Assessment Project has established an Eastern Washington Technical Committee which will determine if other regions or subclasses are needed for eastern Washington wetlands.

Wetlands are not comprehensively identified on the DNR hydrography base map or on topographic maps, and will require the analyst to review other data sources. The National Wetlands Inventory (NWI) maps provide a "first cut" at identifying wetlands and DOE has a complete set of NWI maps in a GIS data base for Washington. However, these maps were drawn using aerial photographs at a very small scale, thus the accuracy of the maps can be poor. Hydric soils mapped on NRCS soil surveys further identify the general areas where wetlands may be found.

Using aerial photographs, an experienced analyst should be able to identify a majority of wetlands in the WAU by noting their distinctive characteristics. For example, major wetlands can sometimes be detected through changes in vegetative composition and structure (e.g., distinct changes from conifer to deciduous trees; trees to shrubs or emergent herbs; and differences in canopy density). Surface water connections are most apparent during high flows. In most cases, stream connections will be apparent. In other cases, field verification may be necessary.

Aerial photos taken at different times in the year, and historical photos, may help identify additional wetlands due to temporal differences in wetland appearance. However, wetland identification presents some unique challenges because of the varied geology and climate found in our state: hydrologic conditions vary due to seasonal variation in precipitation. Wetlands east of the Cascade Mountains can be very different from wetlands west of the Cascades because of the different climate. Wetlands in glaciated areas can have very different characteristics than those in areas that were never glaciated. Lastly, human activities have altered surface and groundwater hydrology, soils and vegetation in many parts of the state. All these elements influence where wetlands are found and what they look like.

Wetland boundaries should be mapped as accurately as possible, but field identification of boundaries is not needed for this assessment. The most critical datum to determine for each wetland is whether it has a surface water connection (either perennial or seasonal) to a stream or river. If a surface water connection is known to exist in a wetland, it is important to draw the boundary of the wetland so it intersects the appropriate stream arc in the DNR hydrographic database.

Form G-1. Wetland Assessment Worksheet

Wetland Identifer	Wetland Hydro-geomorphic Class and subclass	Legal Location	NWI Code (if available)	DNR Wetland Class/Type	Wetland Area (acres)	Open Water Area (acres)	Season Observed	Input Variable	Vulnerability Call (describe situation)	Comments

Local land managers, tribal representatives, other resource professionals, and local residents will be interviewed to obtain information on the location of additional wetlands that may not have been detected. The analyst should coordinate with the stream channel analyst to ensure that riverine wetlands encountered during the channel survey are also included in the wetland inventory. The analyst should coordinate with the channel condition analyst to ensure that wetlands encountered during the channel survey are also included in the waterbody inventory. Special resource characteristics such as deep peat soils and bog environments should be noted where identified.

Multiple-decade photo coverage is necessary to provide a reasonable determination of trends in wetland condition through time. The analyst shall combine time-series analysis of at least 2 sets of aerial photos encompassing the period of photo record for the WAU, anecdotal information, and information derived from field verification to provide a historical perspective and identify gross changes (such as effects resulting from filling and draining or changes in water regime) and resource trends where possible. Changes in vegetative composition based on aerial photographs should be field verified since local environment characteristics (such as aspect, geology, disturbance history) can shift land from upland to wetland conditions. Beaver-impounded wetlands on stream floodplains should also be noted.

Lakes

Lakes will usually be on the DNR hydrography layer and most will also be on the USGS topographic map. The analyst will ensure that lakes within the WAU are put on the Waterbody Map (Map G-1) and that other analysts are aware of them.

Lakes are listed on Form G-2 and key characteristics recorded. These include surface area and estimated depth. Many lakes in Washington have been studied by the DOE or other agencies. The analysts will interview DOE and tribal representatives to determine what may be known about the lake and any known water quality concerns.

Water Supplies

The quality of water is critical to public drinking water and will require assessment by the water quality analyst. Fish enhancement facilities are also often sensitive to changes in water quality parameters. The water quality analyst acquires the location of public water supplies and their point of withdrawal and fish enhancement facilities from the public works/water supply analyst and adds them to Map G-1. The water supply/public works analyst conducts interviews with local water supply personnel to acquire detailed information regarding each facility and will likely contact local resource managers, tribal personnel, and irrigation districts (Form H-1). The water quality analyst will need to know the location and water quality concerns of each identified facility, and will assist the water supply/public works analyst conduct interviews.

Form G-2. Lake Assessment Worksheet

Lake Identifier	Legal Location	Available Data	Area of Open Water (acres)	Approx. Max. Depth of Open Water (feet)	Season Observed	Input Variable	Vulnerability Call (Justification)	Comments

Water diversions and return flows can have a significant effect on water quality in streams and lakes. For instance, reductions in flows can increase water heating in streams or return flows from fields can introduce high levels of nutrients to waterbodies. Evaluation of the effects of non-forestry landuse are outside the scope of analysis. However, the water quality analyst will locate and map the facilities since they may affect the interpretation of data assembled during the analysis.

Upon completion of this phase of the water quality assessment, the analysts will have located and assigned an identification number (e.g., 1, 2, 3, ...) to each major wetland and the lakes and reservoirs, streams, water supply and fish facilities, and nearshore marine/estuarine waters on the Waterbody Map (Map G-1) or, alternately, on the project base map. If unique identification numbers currently exist, such as segment numbers, or identifiers from agencies it is recommended that the analyst use these numbers. Surface water classifications (Class AA, A, B, C, and Lake Class) can be obtained from the riparian analyst or from the Forest Practices temperature standards map and noted on Map G-1. The waterbody identification and mapping process must be completed early in the watershed analysis. The updated waterbody map

(G-1) will then be distributed to all assessment team members so that these resources can be included in their analyses.

Land Use

If other analysts have not done so, the analyst will also develop a Land Use Map (Map G-2) using aerial photography to delineate the general land use classes currently existing (e.g., forested, agriculture, residential). Land use classifications based on remote sensing imagery (e.g., Landsat) may be available in GIS format from local counties or municipalities. This map will be useful as a general reference during assessment and synthesis.

Waterbody Vulnerability Assessment

The vulnerability of waterbody parameters to potential changes in input variables with forest practices is assessed by identifying specific physical conditions where research or past experience in similar watershed situations has documented reasonable likelihood of a water quality response sufficient to exceed criteria. The assessment is intended to be predictive, and a waterbody may be identified as vulnerable based on potential to exceed standards, or, if already affected, its current condition.

This module will identify waterbody vulnerability to some or all of the following parameters: temperature, fine sediment, nitrogen, phosphorus, dissolved oxygen, and pH. (See Table G-1 for module status for all water quality characteristics). It also addresses sediment accretion in wetlands. Which methods are needed in each watershed will depend on the waterbodies present and whether certain watershed conditions are met. It should be noted that identification of vulnerability of a waterbody in this module does not necessarily mean water quality is currently degraded. Also, the finding of a vulnerability of a water quality condition in a stream does not necessarily mean that a vulnerability will also be found in its downstream waterbodies such as lakes, and conversely, a receiving water may accumulate effects that are not detrimental in streams (e.g., nutrients).

Historical and present data, although probably limited, are important along with “modeled” calls based on estimates from watershed conditions. All three should be integrated where available to form the final vulnerability call. The watershed and management history of the area will determine how historical and present data may be informative in relation to the vulnerability determination. Data may either confirm or deny a hypothesis. Where data alters a hypothesis, the analyst should record their justification for changing the determination.

The methods are organized by water quality parameter. Within each parameter, a flowchart guides the level and steps of analysis, in some cases providing a vulnerability determination based on simple screening variables. A vulnerability map for each parameter is produced for use by all analysts in synthesis to identify potential sources of adverse impacts to vulnerable waterbodies, although if only low vulnerability is found no map will be included among the module products. For temperature and sediment effects, there usually is reasonable potential for effects from forest practices if adequate protection is not provided, and these assessments will nearly always be included. Vulnerability of dissolved oxygen and pH is rarely found and the need for analysis of these parameters is not common.

The analyst should refine the area of water vulnerability. Recognizing that water quality impacts are affected by factors that dilute or accumulate within the watershed, the assessment of each parameter should be limited to the zone of influence of the waterbody, if it can be determined. This zone of influence will be specified as a Water Quality Map Unit (WQMU) and mapped on the Water Quality Vulnerability Maps. The standard assessment allows the entire contributing watershed to be considered unless specified in the assessment criteria. A level 2 assessment may broaden or narrow the zone based on rationale or information documented in the watershed report. The WQMUs are coded on the maps by water quality parameter and input variable (e.g. Water Temperature Vulnerability to Shade Removal or Dissolved Oxygen Vulnerability to Organic Matter/Slash Input).

Water Temperature Assessment

Scientific Background

Water temperature is a fundamental parameter of water quality and an integral component of aquatic habitat. Chronic and significant water temperature exceedances above the natural variability of a stream are likely to impact the aquatic biota (e.g., Hynes, 1970; Beschta et al., 1987). Furthermore, elevated temperatures can trigger conditions which affect other water quality parameters such as dissolved oxygen. Local and downstream changes in temperature associated with shade removal is an important land use consideration. Table G-6 lists the natural watershed parameters that are most influential in determining stream temperature. These include: solar radiation, air temperature, stream width, stream depth, shading, and groundwater inflow. Forest practices can affect these parameters. For example, removal of riparian vegetation increases the solar radiation received by a stream reach; logging can alter streamflow, either decreasing or increasing summer low flows depending on local situations, and sedimentation can decrease channel depth and increase channel width.

Table G-6. Types of Variables Affecting Stream Heating Processes
(from Sullivan et al. 1990)

General Variable	Example
Geography	latitude, longitude, elevation
Climate	air temperature, relative humidity, wind velocity, cloudiness
Stream Channel Characteristics	stream depth, width, velocity, substrate composition, water clarity
Riparian or Topographic Blocking	sky-view (% shade), canopy density, vegetation height, crown radius, topographic angle

Many studies conducted throughout the United States have documented the effects of riparian vegetation and its removal on summer stream temperatures with consistent results (reviewed by Beschta et al., 1987). Brown and Krygier (1970) demonstrated that reduced stream shading results in generally higher stream temperatures and increased diel temperature fluctuation.

There is natural variability in the vulnerability of waterbodies to shade removal due to differences in their size and location within the watershed. The magnitude of potential temperature change with removal of streamside vegetation varies with stream depth (Brown, 1969; Adams and Sullivan, 1990; Sinokrot 1993). Shallow streams have the greatest response while change in larger, deeper streams is less. In the case of streams, the farther from the watershed divide, the less influential is riparian vegetation in maintaining temperatures as channels naturally widen as they convey more water. The wider the waterbody, the taller the vegetation must be to effectively block the view-to-the-sky. Large lakes are often too wide for any vegetation to be an effective control of water temperature. Small or moderate-sized lakes may not be fully shaded but they can still be affected by the blocking of radiation by streamside vegetation. The ability of vegetation to block incoming and outgoing radiation depends on its height relative to the width of the waterbody. Along very small streams almost any vegetation and streambanks themselves will provide shade, while tall trees and major topographic features are necessary for significant shading of larger rivers. The maximum potential shade depends on the features of native vegetation.

The DOE classification of rivers and streams partially accommodates this natural variability (Table G-7). Streams near headwaters are usually forested and are generally classed as AA with expectations of cool water temperature. The boundary between AA and A streams generally occurs a significant distance downstream from headwaters but the location has been assigned for each river according to several criteria, and may not reflect the natural capability of the river to achieve water temperature conditions. Similarly, the boundary between A and B streams is generally found much lower in the watershed and may be assigned for a variety of reasons besides water temperature.

Table G-7. Water Temperature Standards

DOE Waterbody Classification	Annual Maximum Temperature	Incremental Increase
Class AA Waters	16.0º C (61º F)	<2.8º C (5º F)
Class A Waters	18.0º C (64º F)	<2.8º C (5º F)
Class B Waters	21.0º C (70º F)	<2.8º C (5º F)

An extensive study of temperature in Washington streams confirmed relationships between temperature, watershed and landuse factors established in previous research (Beschta et al., 1987). The study was also able to identify a simple relationship between view-to-the-sky and elevation that could be used to predict the maximum allowable view-to-the-sky that would maintain temperature within water quality criteria for purposes of guiding riparian area management in state forest practice regulations. Documentation of the basis of the simple model is provided in Sullivan et al., 1990, see chapters 6 and 7). Relationships for streams east and west of the Cascade Mountain divide have been adopted as the temperature screen by the Washington Forest Practices Board (WFPB 1993) to be used in managing riparian areas for protecting shade on a site by site basis. This screen demonstrates that less shade is needed at higher elevations than lower elevations to maintain the same water temperature.

The methods presented in this module estimate expected changes in annual maximum stream temperature at a stream-reach scale, based on different scenarios of riparian vegetation type and extent, and hence, different degrees of shading provided by the riparian vegetation. Many important aspects of the physical processes and geomorphic conditions controlling water temperature at a basin scale are reviewed as scientific background in the Appendix of this module. Derivation of analysis techniques and simple models used in steps of this assessment are provided. Water quality analysts must familiarize themselves with these principles in order to conduct the water quality module and synthesis steps determining temperature vulnerability.

The degree of vulnerability of water temperature to forest practices is determined by the relative importance of riparian vegetation in limiting view-to-the-sky sufficient to maintain water temperature within the standards. Stream water temperature is considered vulnerable if the maximum temperature is capable of exceeding state water quality criteria.

Although temperature is primarily assessed in relation to the shade provided by riparian vegetation, there may also be secondary effects on temperature from other watershed disturbances. For example, sedimentation may widen the channel and increase view-to-the-sky. Water depth may also be reduced with sediment accretion or water withdrawals, although this effect is expected to be relatively less important than increased exposure except in more extreme cases of sedimentation or where cool water refuges are lost. Identifying these effects on temperature from causes other than direct shade removal is also an important product of watershed analysis although these determinations will be made in interdisciplinary analysis during synthesis. During watershed synthesis, the water quality analyst must work with other analysts and the products they developed from the hydrology, mass wasting, habitat, channel and riparian modules, as well as ancillary data on fisheries resources, in order to develop an integrated assessment of the likely effects of forest practices on stream temperature.

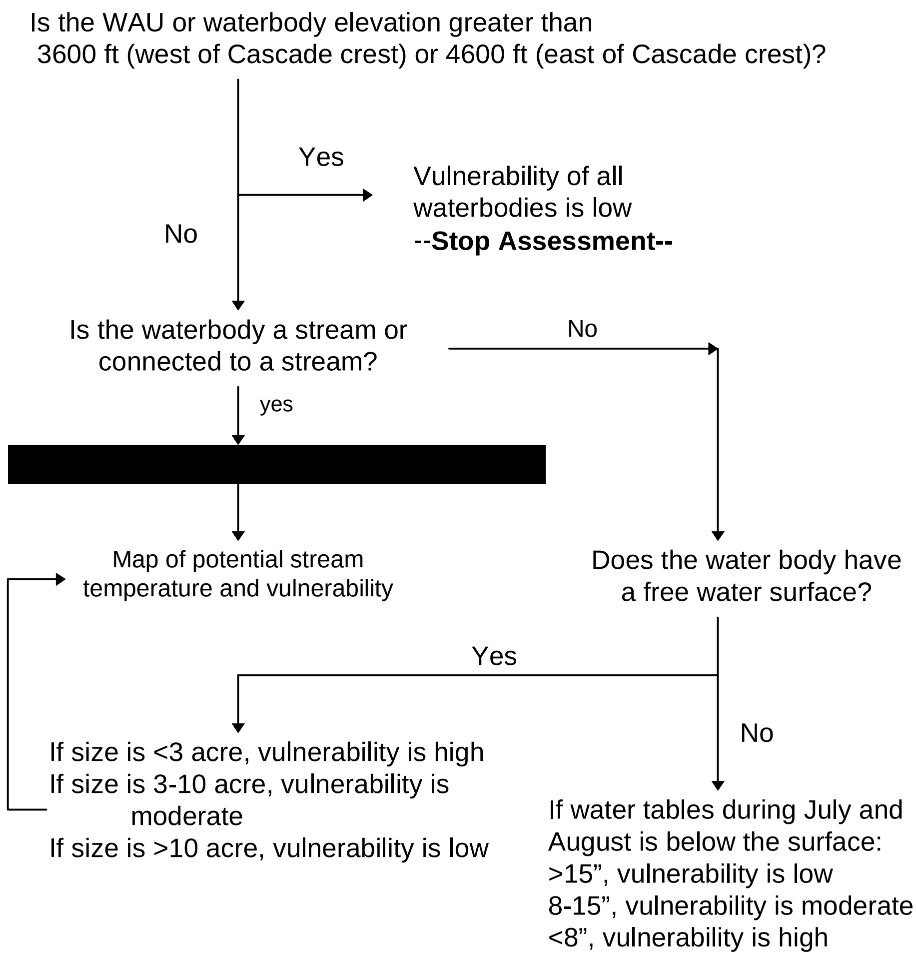
Assessment

The vulnerability of waterbodies within the WAU to shade removal is determined by different procedures, depending on whether they are riverine and flowing or wetlands with water above or below the ground surface (Figure G-3). Several “screening level” criteria can be used to indicate whether temperature assessment for particular waterbodies is needed at all. No temperature assessment is needed if waterbodies are at very high elevation (>3600 ft west side of the Cascades and >4600 on the east side of the Cascades). High elevation streams and lakes are unlikely to have high water temperatures, regardless of shade conditions according to results of the TFW Temperature study (Sullivan et al. 1991). Assessment will be necessary for all streams and riverine wetlands that are not at high elevation. The necessity for assessing isolated wetlands and lakes depends on the surface area of the waterbody. Shallow seeps may also be susceptible to temperature increase with shade removal, depending on the proximity of the water table to the ground surface.

Many of the assessment products described in this module were produced by the riparian analyst as part of the shade assessment portion of the riparian module in previous versions of the Watershed Analysis Manual. The water quality analyst should obtain these products from the riparian analyst to avoid duplication of effort, or the riparian analyst may produce the additional products specified in this module and complete this water quality module temperature assessment. The water quality module provides methods for all products relating to reference temperature and vulnerability to shade removal while the riparian module provides methods for products relating to current shade and hazard to shade loss. Products of the water quality module assessment include maps and determinations of vulnerability to shade loss.

Figure G-3. Temperature Analysis Flow Chart

(Criteria are developed in the text.)



Level 1 Stream Temperature Procedure

Temperature vulnerability assessment is primarily oriented to evaluating potential effects on water temperature from removal of vegetation. The analyst determines minimum potential view-to-the sky considering the relationship between mature vegetation height and channel width as it controls the openness of the channel. View-to-the-sky estimates are coupled with the temperature screen to estimate potential temperature. Vulnerability is determined considering the difference between potential view and the maximum allowable view that will maintain water temperature criteria. From this information, a map of potential water temperature in the watershed and the vulnerability is produced.

The basic steps of the stream temperature assessment are:

1. ***Map potential view-to-the-sky based on estimates from mature vegetation,***

2. ***Map maximum allowable view-to-the sky based on elevation/sky view relationship,***

3. ***Map reference temperature for each stream segment or riparian unit,***

4. ***Determine vulnerability to shade loss,***

5. ***Complete map products.***

Steps:
Calculating potential and maximum allowable view-to-the-sky requires the use of a topographic map as a working map. Estimates of potential and maximum view are recorded on the map according to methods described in this section.

1. **Map potential view-to-the-sky based on mature or old growth forests.**

The first step in the temperature vulnerability analysis is to determine the view-to-the-sky that would likely occur under the assumption that fully mature forests populated the entire watershed. This establishes the minimum potential view-to-the-sky. The analyst estimates the potential view-to-the-sky assuming the potential height of older mature trees native to the site and vegetation density. Channels up to 20% gradient identified by the channel and riparian analysts are included in the assessment. Smaller or steeper channels not on the basemap can be assumed to have potential view-to-the-sky of 0.

If data on minimum view-to-the-sky is available from the area based on measurements of fully stocked and fully grown forest stands, then this may be used as a basis for this analysis. Many watersheds with past landuse or natural disturbance are likely to have vegetation on some or all stream segments that do not currently match these criteria. In the absence of reliable empirical relationships between potential view-to-the-sky and easy to determine watershed measures such as distance from divide or basin area, the analyst may estimate using hypotheses of channel dimensions and geometric characteristics of forest stands of appropriate species as described in the remainder of this section.

The following analysis demonstrates how to estimate view-to-the-sky directly from the geometry of the riparian setting. Calculating view-to-the-sky with the mathematical model requires knowledge of stream width between trees on either bank. If measured widths are unavailable, bankfull width can be used as a suitable surrogate. (For purposes of estimation, no attempt is made to include shade that may be provided by vegetation growing in mid-channel bars. Level 2 analysis could further investigate this effect).

Measurement of bankfull width is preferable. However, to extrapolate results to or from other watersheds, bankfull width may be estimated using hydraulic geometry relationships (Leopold et al. 1964, Dunne and Leopold 1978). Water depth may be estimated similarly. It may be assumed that channel width is a function of discharge of the form:

$$\text{Width} = aQ^f \qquad (1)$$

$$\text{Depth} = bQ^g \qquad (2)$$

where Q is discharge, and a and f are coefficients that may vary from watershed to watershed. Since Q increases with basin area, a similar form exists for estimating channel dimensions using basin area:

$$\text{Width} = bA^m \qquad (3)$$

$$\text{Depth} = cA^k \qquad (4)$$

This relationship, once established for the watershed, can be used to estimate channel width using basin area. To calibrate estimates, riparian and channel module analysts may be able to provide measured data from the watershed. Stream segments may be naturally wider or narrower than this general estimate, resulting in under- or overestimation of vulnerability. Local interactions between waterbody width and valley topography can be accounted for in field investigation.

To calculate view-to-the-sky, determine the angle, a (in degrees), from the horizontal formed by the wall of trees, and substitute into the formula:

$$\propto = \text{ArcCos}\ (w/\ \text{SQRT}\ (w^2+4h^2)) \qquad (5)$$

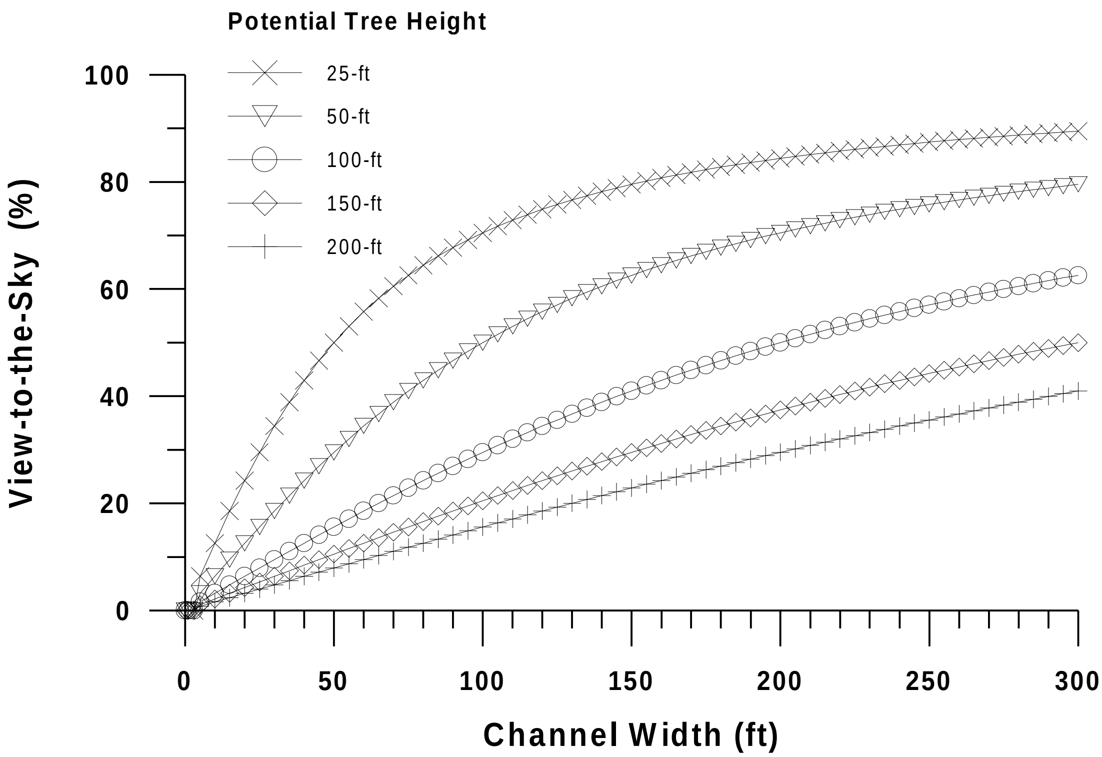
where w is the stream width and h is the height of the trees.

Calculate view-to-the-sky using angle $\propto$ using

$$\text{View-to-the-sky (\%)} = 100 - \frac{10}{9} \propto \qquad (6)$$

This equation was solved for a range of stream widths and potential tree heights in Figure G-1.

Figure G-1. Calculated view-to-the-sky in relation to potential tree height based on equation (6)



Several assumptions are made to determine potential view-to-the-sky calculations based on geometric relationships. Maximum potential height of native overstory species is assumed to be the height of blocking vegetation (h). Potential view-to-the-sky is determined by making the above calculations based on the site as it could be with mature vegetation (whether shrub or trees). The analyst must assume an appropriate height of the forest stand or shrub community that would occupy the site under historic natural conditions. The chosen height should be representative of vegetation that has reached mature height (potential height). Analysis of available riparian shade data from western Washington suggests that a height of 150-ft should be used in calculations for western Washington unless site data is available (see the Appendix attached at end of module).

Estimates may be improved by actual field measurement, including both change in potential tree height and an opacity factor. View-to-the-sky can be calculated by the same formula given above, but substituting effective tree height He for H. An additional correction may be needed if the trees are sparse. Use of an opacity factor should be based on field estimates from reference sites and should be ignored if these are not available. Opacity is already included in the recommendation of 150-ft potential tree height.

It is also assumed that blocking elements are the same on both sides of the stream. Analysts may alter estimates along stream systems where the assumptions can not be met. Bankfull stream width (w) is assumed to be the maximum distance between blocking elements on opposite banks.

Include the estimated potential view-to-the-sky on the working Temperature Vulnerability Map. An example is provided in Figure G-3.

2. Map minimum potential view-to-the-sky based on the TFW temperature screen elevation/view relationship (see Tables G-8 and G-9).

In this step, the analyst determines the minimum view necessary to maintain temperature within Washington water quality standards for annual maximum temperature. The analyst uses the relationship between view-to-the-sky and elevation based on empirical measures from rivers in Washington reported by Sullivan et al. (1990) and included in the Forest Practice Regulations (WAC 222). Values for maximum allowable view-to-the-sky (S) are provided for western Washington in Table G-8 and eastern Washington in Table G-9. Note that the elevation zones for the AA and A standard are provided in the tables. The calculations for baseline temperature described in this section are adjusted relative to class AA standards. Therefore, use view-to-the-sky from the class AA elevation categories for constructing the reference temperature map.

The maximum allowable view-to-the-sky is recorded in 10% increments on the working temperature map based on change in elevation. Boundaries between the potential and allowable view will not necessarily overlap.

Table G-8. Maximum allowable view-to-sky for non-glacial streams in western Washington.

	Elevation Zones (feet)	
Maximum Allowable View-to-the-sky (%)	**Class AA DOE standard = 16.0° C**	**Class A DOE standard = 18.0° C**
>90	>3600	>2320
90+	3280-3600	1960-2320
80+	2960-3280	1640-1960
70+	2400-2960	1320-1640
60+	1960-2400	1000-1320
50+	1640-1960	680-1000
40+	1160-1640	440-680
30+	680-1160	120-440
20+	<680	<120

Table G-9. Maximum allowable view-to-sky for non-glacial streams in eastern Washington.

	Elevation Zones (feet)	
Maximum Allowable View-to-the-sky (%)	**Class AA DOE standard = 16.0° C**	**Class A DOE standard = 18.0° C**
>90	>4450	>3900
90+	4200-4450	3700-3900
80+	4000-4200	3450-3700
70+	3800-4000	3250-3450
60+	3600-3800	3050-3250
50+	3350-3600	2850-3050
40+	3200-3350	2600-2850
30+	2900-3200	2450-2600
20+	2750-2900	2200-2450
10+	<2750	<2200

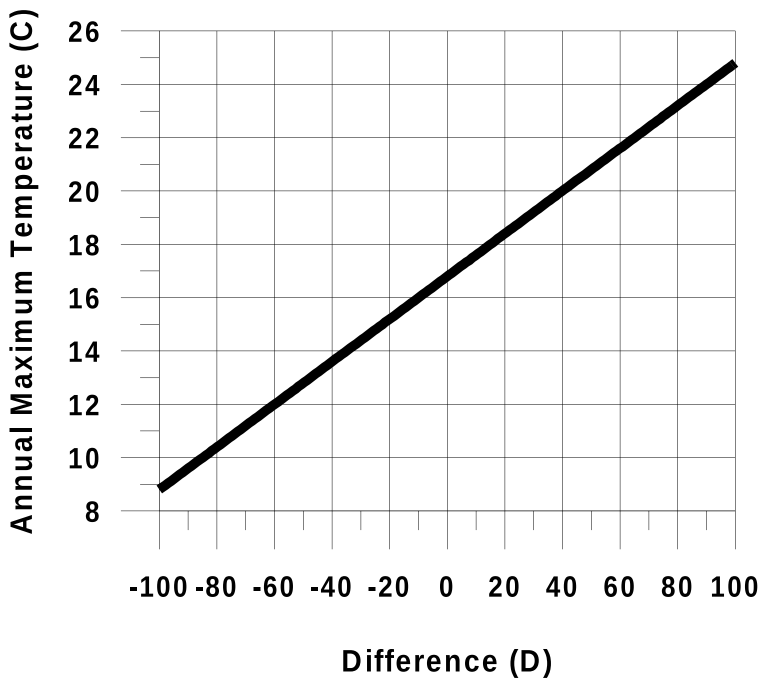
3. **Determination of Reference Temperature.** In this step the analyst estimates the potential water temperature under mature vegetation conditions. This is accomplished by relating the maximum allowable view-to-the-sky with estimates of potential view with mature vegetation. Temperature is determined by comparing the difference in minimum and allowable view-to-the-sky to Figure G-3 :

$$D = V - S \tag{7}$$

where D is the difference in view factors (%), V is the potential view-to-the-sky (%) and S is the maximum allowable view-to-the-sky (%) determined from the temperature screen in the previous step. These values have been plotted on the working temperature vulnerability map in previous steps. Calculation of D should be performed for each stream reach where either the potential view or the maximum allowable view changes.

To estimate the reference temperature, compare the calculated difference D to Figure G-2. Read the temperature from the line corresponding to D. The scale is based on the temperature screen observed relationships between view and temperature reported in Sullivan et al. (1990). This method is a first approximation for annual maximum water temperature and is not expected to be able to precisely predict the location where water quality exceedance is likely to occur. Other modeling techniques for estimating annual maximum temperature may be substituted (provide rationale and description of methods).

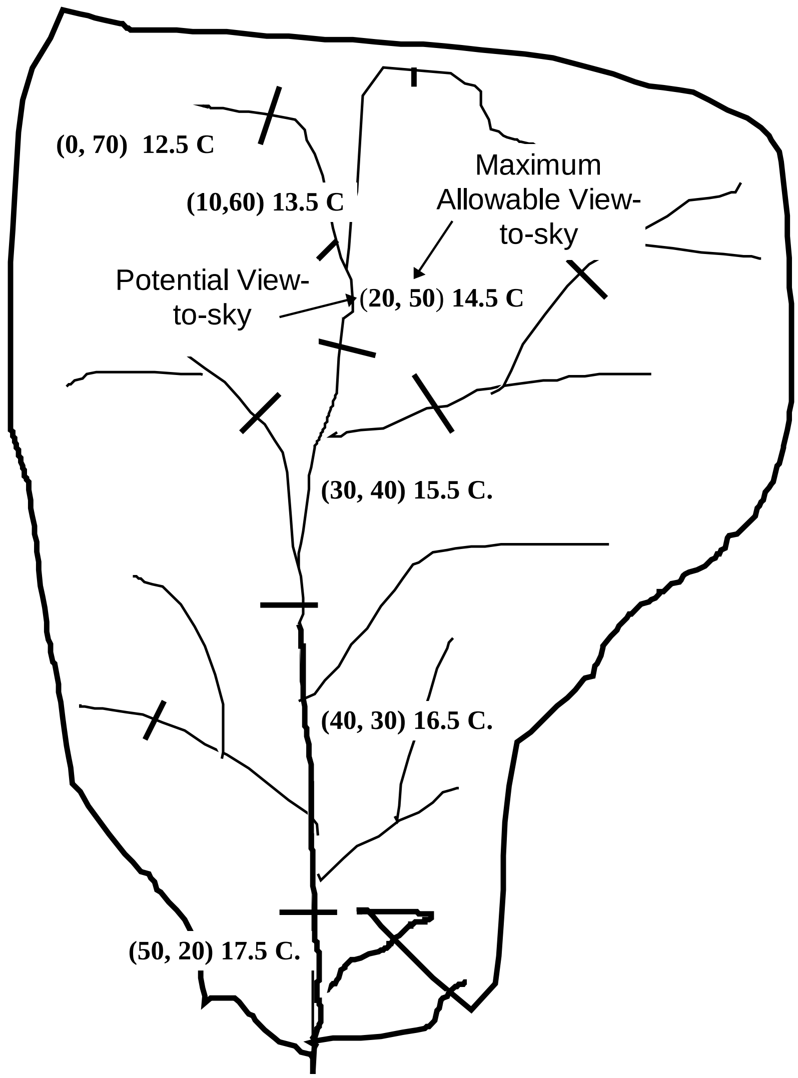
Figure G-2. Scale for comparing potential view to minimum view determined from the temperature screen to estimate reference temperature



Differences can range between -100 and +100 although most streams in Washington are likely to plot between -60 and +60 based on data from the TFW temperature study. This estimate suggests that maximum temperature may vary from 9-25 degrees C. in the portion of the basin affected by shade (Figure G-2). These values are close to the range or annual maximum temperature observed in Washington forested streams which typically fall between 10 and 25^{o} C (Sullivan et al., 1990) as well the range of response to forest removal reported by Brown and Krygier (1970).

Using Figure G-3 and the values of potential and minimum view plotted on the working temperature map, the analyst creates a map that is a first approximation of potential water temperature in the WAU assuming mature forest (Figure G-3). This map may provide a useful comparison with current view-to-the-sky maps created by the riparian analyst from which a similar estimate of temperature at current view-to-the-sky can be calculated or if water temperature data is available.

Figure G-3. Example of Reference Temperature Map (Map G-3)

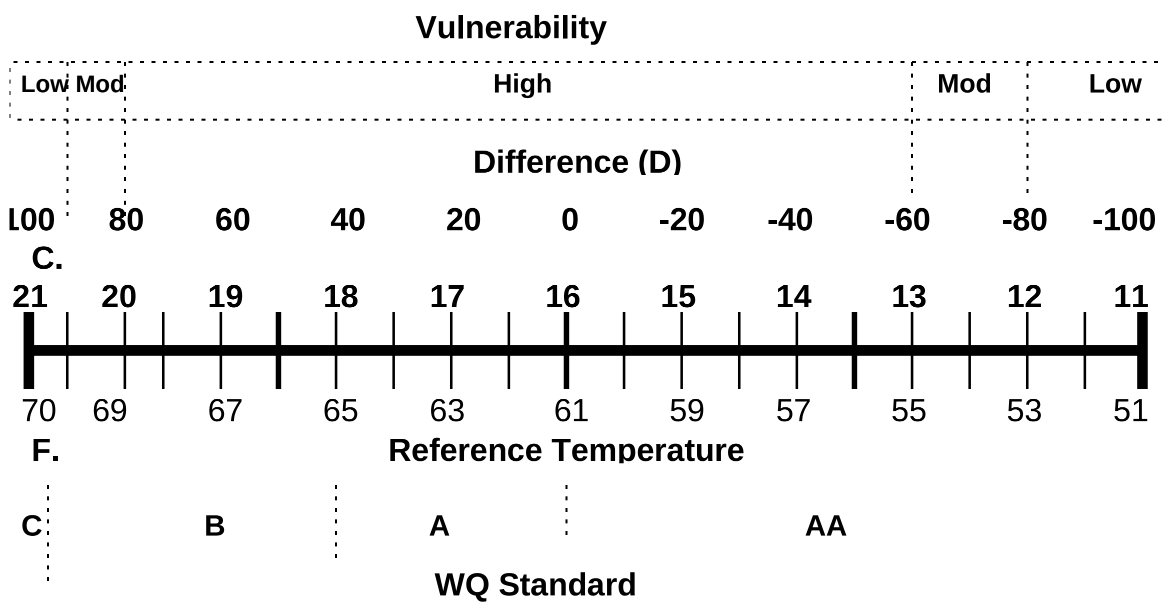


4. Determine Temperature Vulnerability

The temperature of streams flowing during the warm summer months is vulnerable if shade removal is likely to result in exceedance of either the maximum or incremental water quality temperature criteria. All locations in the river system where the channel is wider than that associated with the potential view that resulted in D>+90 are probably very warm but are not vulnerable to removal of shade. All locations where D is less than +90 probably have some influence from streamside vegetation.

The vulnerability is determined from the scale provided in Figure G-4 using the view difference (D) and reference temperature determined in earlier steps. The diagram in Figure G-3 has been assigned vulnerability categories considering both the maximum and incremental criteria. These categories serve as guidance in selecting appropriate vulnerability based on likely response to shade removal. The analyst may further refine vulnerability based on specific location on the graph and local situations (provide justification for interpretation.) Effects of shade removal or addition and likely temperature response can be evaluated by moving up or down along the central line.

Figure G-4. Vulnerability determination is based on the scale at the top of the figure. Also marked at the temperature ranges associated with the DOE water type classification.



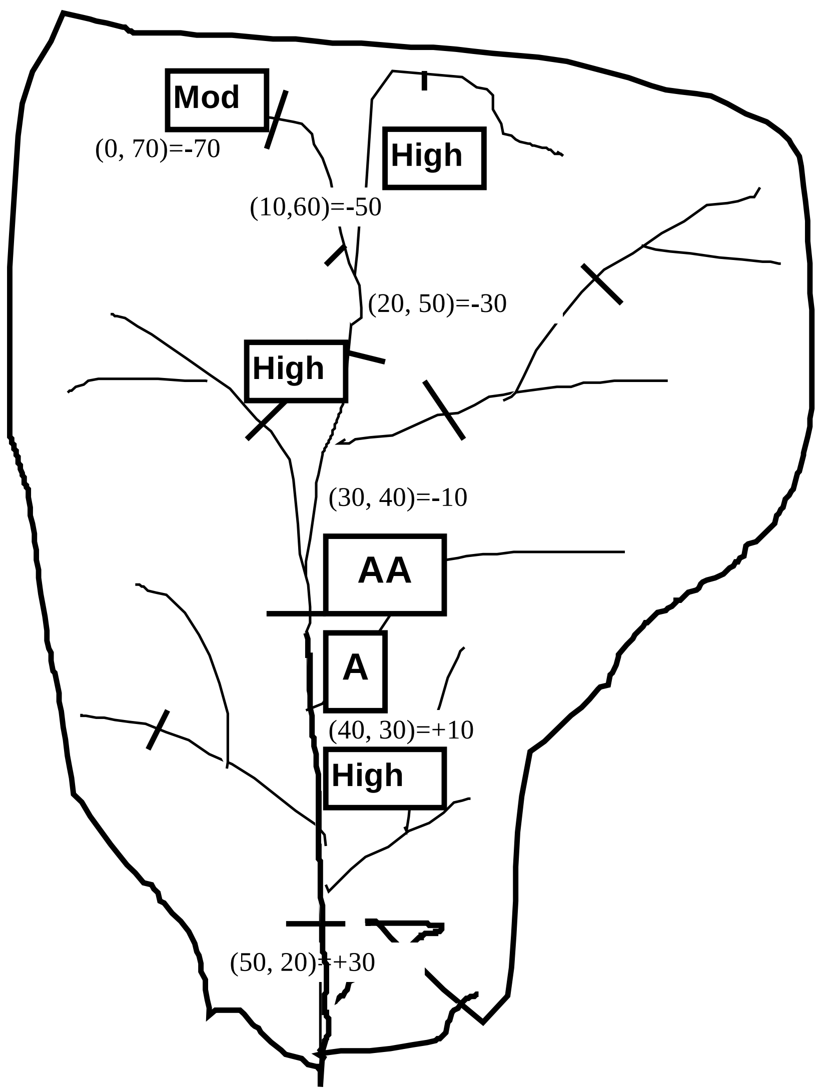
5. Complete map products (Maps G- 3 and G-4)

The analyst shall begin to prepare a Water Temperature Vulnerability Map (Map G-4) which should include: potential view-to-the-sky, maximum allowable view-to-the-sky, vulnerability (high, moderate, low), achievable temperature based on the difference between potential and minimum required view, water quality classification (AA, A, B, C). Include locations where temperature has been monitored, if any. Any temperature sensitive public works (e.g., fish facilities) should also be located on this map. An example of the map product G-4 is provided in Figure G-5. Temperature vulnerability assessment for other waterbodies will be added to this map. Determinations should be recorded on the Stream Temperature Vulnerability Worksheet-Form G-3).

The potential temperature map can also be used by the analyst to evaluate the relationship between water quality standards currently assigned by the

DOE by stream classification relative to the natural temperature patterns expected in the watershed based on vegetation and topographic analysis. Given that waterbodies were classified considering a variety of water quality conditions including fecal coliform, dissolved oxygen, temperature, and pH, there may be discrepancies between achievable and classified temperature.

Figure G-5. Example of Temperature Vulnerability Map G-4.



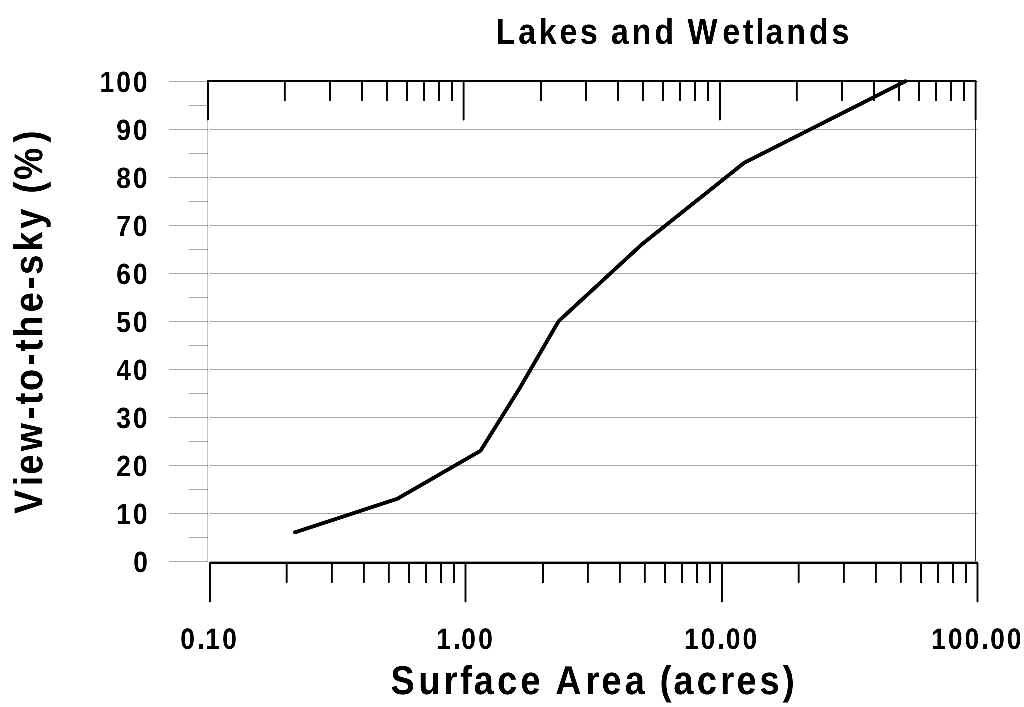
Form G-3. Format for Stream Temperature Vulnerability Worksheet

Distance (mi.) or segment #	Channel Width (ft.)	Wetted Channel Depth (ft.)	Potential Sky-View (%)	Maximum Allowable Sky-View (%)	Current View-to-the-sky (%)	Potential Difference (%)	Current Difference (%)	Estimated Reference Temp (°C)	Estimated Current Temp (°C)	Measured Temp (C) if known	W.Q. Standard	Vulnerability Call

Temperature Vulnerability of Other Waterbodies

Water temperature in waterbodies other than streams is determined by the same heat transfer processes as streams. Lake size (and probably elevation) can be used as an effective screen for identifying where water temperature vulnerability to forest practices exists. The same geometric hypotheses described in detail in previous sections also apply to lakes and wetlands. However, these waterbodies were assumed to be round and the appropriate geometric calculations are based on spheres rather than lunes. The results of these calculations are provided in Figure G-6. Calculations assume 150-ft effective tree height and that the waterbody is round.

Figure G-6. Estimated view-to-the-sky as a function of surface area of waterbodies other than streams.



Standard Assessment: Assuming potential tree height, waterbodies less than 3 acres have high vulnerability to temperature effects from forest practices assuming waterbodies are close to round in shape. Waterbodies between 3 and 10 acre have moderate vulnerability. Larger waterbodies have low vulnerability.

Level 2 Assessment: Use native vegetation characteristics and waterbody dimensions to determine whether potential view-to-the-sky is less than 50% (moderate vulnerability) or less than 80% (low vulnerability.) The analyst may chose the appropriate geometric shape for the waterbody for use in calculating the hemisphere area blocked by vegetation. If the waterbody is relatively linear, the same calculations based on the lune shape where width is averaged for the waterbody may be used. If water temperature information is available for the waterbody, the analyst may wish to attempt to use the same method for determining vulnerability of the waterbody in a manner similar to that used for determining the vulnerability of the streams.

For wetlands whose water surface is below the ground surface but that discharge groundwater to streams, there may still be vulnerability to shade removal if the water table is near the surface during the months of July and August. Although soil and gravel is a relatively poor conductor of heat, the surface layers will experience diurnal fluctuation in response to solar radiation just as the water will (Chen at al.1995). Information on heat flux in streambed gravels was used to derive criteria in Table G-10 (Ringler and Hall 1975, Comer and Grenney 1977, and Sinokrot and Stefan, 1993). Use the following vulnerability determination for riverine connected wetlands with shallow water tables:

Table G-10. Vulnerability of Wetlands with Shallow Water Tables

Vulnerability	Criteria
High	Water table <8" (20cm) below the ground surface (July-August)
Moderate	Water table 8-15" (21-38 cm) below the ground surface (July-August)
Low	Water table >15" (38 cm) below the ground surface (July-August)

Water Supplies

Public works (water supplies and hatcheries in particular) have need for cool water and are likely to be vulnerable to temperature increases. Usually water suppliers will have information on temperature and a clear understanding of the temperature vulnerability. The water quality analyst will consult with the public works analyst to determine the temperature vulnerability of water supplies occurring in the watershed. It will be useful during Synthesis for the water quality analyst to determine the zone upstream of waterbodies that potentially affect water temperature. This distance will vary with stream size: the smaller the stream, the more local the zone of influence. For smaller streams (type 3), the zone upstream where shade removal can influence temperature at downstream locations is up to 2000-ft (600m). For type 1 and 2 streams the distance considered should be 5000 ft because of faster travel time and deeper water which responds more slowly to environmental conditions (Sullivan and Adams,1990). For type 4 streams, the influence is not likely to extend more than 1000 feet. However, local stream conditions may vary the distance estimates depending on water depth, groundwater inputs, and velocity. Distances may be longer or shorter.

Level 2 Assessment
Estimates of water temperature based on Level I assessment rely primarily on generalized relationships between watershed, channel and vegetation characteristics. Although the temperature prediction model is expected to be an approximation of potential temperature, estimation may be improved by better quantification of variables included in the Level I method. For example, measurement of stream width and depth to determine the hydraulic geometry for the WAU is preferable to estimates based on data from other watersheds or regions. The Level I method uses width to calculate view-to-the-sky from assumed vegetation characteristics (this module) and current vegetation (riparian module) to estimate potential and current temperature. Variation in width due to natural or man-caused disturbance can be accounted for in estimation of temperature by altering view-to-the-sky appropriately. In addition, vegetation calculations assume dense (closed) stands of fully mature native vegetation. View factors may be modified with the use of an opacity factor to improve representation of potential or existing stands with species or density characteristics different than the assumed value. Significant blocking topography can be accounted for by increasing tree height according to hillslope gradient.

The simple temperature prediction model included in Level I assessment only accounts for view-to-the-sky, channel width, and elevation in estimating temperature. Although some provision for local variability in these factors can be achieved, other variables that are known to influence water temperature are not considered in the Level I method and these can be locally important in controlling temperature and may be affected in combination by changes in various input factors. If more precise definition of temperature is desired for vulnerability or hazard determination or cumulative effects analysis, the analyst should use a computer-based temperature model such as TEMPEST (Sullivan et al., 1990) where site factors can be more precisely accounted for. Basin models are not recommended at this time since they tend to predict poorly and have significant data requirements.

Finishing Temperature Assessment

1. ***Combine information about streams and lakes on the Working Temperature Vulnerability Assessment Map, (the existing shade will be added to the map by the riparian analyst).***

2. ***Produce Reference Temperature Map (G-3).***

3. ***Produce final stream Temperature Vulnerability Map (G-4).***

4. ***Notify riparian analyst if there are any special shade assessment needs to be completed prior to the synthesis phase of watershed analysis.***

5. ***Coordinate with channel and public works analysis to determine if there are any special assessment needs.***

Sediment Accretion in Wetlands

Scientific Background

Forest management can have both short and long-term effects on the production and routing of sediment to waterbodies. Road building, road use, yarding and removal of vegetation from hillslopes can affect erosion processes, including landslides and other rapid mass wasting processes, slumps and earthflows, surface erosion, and channel bank erosion. The relative extent to which these processes account for forest practice-related sediment impacts to water quality varies among the different forested regions of Washington and locally within regions, depending on topographic, geologic and climatic conditions.

State water quality standards (Chapter 173-201A WAC) include both numeric and narrative (i.e. descriptive) criteria that apply to sediment-related impacts. Numeric criteria for turbidity prohibit an increase of 5 NTU, or 10% over background levels, whichever is greater. No numeric criteria exist for other characteristics of sediment.

The effects of coarse sedimentation are evaluated in the stream channel and fish habitat modules.

The purpose of this assessment is to determine whether forest practices are likely to increase the rate of both fine and coarse sediment accretion in wetlands, thereby impairing wetland functions. Primary assumptions include:

- the rate at which sediment is delivered and stored will influence the physical and biological properties of a wetland

- excessive accumulation of sediment in wetlands is detrimental, affecting resource characteristics and reducing valuable wetland functions such as water storage and discharge, energy dissipation, nutrient cycling, as well as habitat suitability

- the vulnerability of a wetland to sediment and concomittant reduction of functional values can be assessed by evaluating the likelihood that sediment will be delivered and stored by the wetland in excess of natural levels

- the chance that a wetland will receive sediments is dependent on topography, the degree of connection to the stream system that would transport sediments, soil type and extent of disturbance

- the vulnerability of a wetland increases as a wetland's effectiveness at trapping sediments increases because more sediments will be retained to affect existing functions

For the purposes of this assessment, it is assumed that sediment accretion beyond natural background rates may negatively affect existing wetland functions, and that wetlands are considered vulnerable to forest practices if management activities will significantly alter the amount of sediment routed to, and retained by, the wetland.

The ability of wetlands to store sediment varies significantly. There are some general properties that may be applied to all wetlands with respect to their ability to trap sediments. These properties are: water velocity, residence time, available sediment, and sediment base level as follows:

The *velocity* of water must be fast enough to transport sediment to the wetland and then slow enough through the wetland to allow the sediment to be deposited there.

The residence time of the water is the length of time it remains in the wetland. Generally, long residence times are necessary to allow the clay faction to settle out of the water column. As the residence time increases, so does the proportion of the sediment load that will be deposited in the wetland.

Available sediment refers to the amount of sediment that is transported to the wetland. If more sediment is delivered to the wetland than can be transported away, it will accumulate.

The *sediment base level* is the level above which there can be no deposition. As the level of the sediment-water interface approaches base level, vertical accretion rates diminish and deposits tend to accumulate horizontally where possible.

Vulnerability Assessment

The vulnerability of a wetland to sediment accumulation and associated reduction of functional values will be assessed by evaluating the likelihood that sediment will be delivered and stored by the wetland. Establishing the vulnerability of the wetland to sediment accretion requires an assessment of characteristics that determine the probability that sediments will reach the wetland and the effectiveness with which they are trapped by the wetlands in the WAU.

Probability assesses the chance that a wetland will receive sediment carried by streams and rivers from upstream locations in the watershed. The chance that a wetland will receive sediments from stream sources is dependent on the degree of connection to the stream or overland flow systems that would carry the sediments. The probability, and thus the vulnerability, increases as the connections between the wetland and stream increase because the wetland is "accessible" to sediment loads that are higher than "normal." Probability is assessed based on a wetland's position in the landscape as determined by its HGM subclass, site topography and hydrology.

Effectiveness assesses the capability of a wetland to store sediment. Two variables are important in assessing a wetland's effectiveness at trapping sediments: velocity of water through the wetland and the roughness of the surface. Two indicators of velocity are to be used: gradient and type of outlet. The indicator for roughness will be the extent of vegetation cover in the wetland.

Generally, the higher the probability and effectiveness, the higher the vulnerability to sediment filling. Table G-11 provides the decision matrix for assigning vulnerability ratings based on probability and effectiveness.

Table G-11. Vulnerability determination based on rating of probability and effectiveness

	EFFECTIVENESS		
PROBABILITY	**High**	**Moderate**	**Low**
High	high	high	moderate
Moderate	high	moderate	low
Low	moderate	low	low

Level 1 Assessment

The information needed by the analyst to do a Level 1 assessment is the inventory base map of wetlands in the WAU and their HGM Subclass. At this point, the analyst establishes a general rating for the HGM Subclasses, relying upon remote sensing with very limited field verification. This first-level assessment is based on the probability of sediments reaching a wetland, as determined by its hydrogeomorphic classification, and ratings for effectiveness based on presumptions regarding the HGM classification. The following rationale is used for rating probability and effectiveness:

Riverine Flow-Through - Probability that sediments will reach the wetlands is High because the surface water connection to the stream carrying sediment will facilitate transport to the wetland. This is especially important during overbank flooding. The default for effectiveness is Moderate because the characteristics of effectiveness have not been determined.

Riverine Impounding - Probability that sediments will reach the wetland is High because the surface water connection to the stream carrying sediment will facilitate transport to the wetland. The default for effectiveness is High because sediment deposition occurs where water velocity rapidly slows as a result of constriction or increased cross-sectional area.

Depressional Flow-Through - The probability that sediments will reach the wetland is Low because sediments may only reach the wetland from surface runoff in the surrounding watershed. The rating is low because it is assumed that most of the sediments will be retained before they reach the wetland. The rating for effectiveness is Moderate because the velocity of water in the wetland is expected to be low regardless of other conditions. By definition, depressional wetlands are found in topographic depressions which by their geomorphic setting will collect and hold water. Depressional wetlands are effective traps for sediment because they have constricted outlets and pond (i.e. slow down) water.

Depressional Closed - The probability that sediments will reach the wetland is Low because sediments may only reach the wetland from surface runoff in the surrounding watershed. The rating is low because it is assumed that most of the sediments will be retained before they reach the wetland. The rating for effectiveness is High. Sediment retention in wetlands without outlets approaches 100 percent because flow is totally stopped.

Slope Connected - The probability that sediments will reach the wetland is Low because sediments will only reach the wetland by surface erosion from overland flows. These overland surface (sheet) flows tend to be low in volume because the catchment areas tend to be small. Most of the water in slope wetlands comes from groundwater seeps. The default for effectiveness is also Low because connected slope wetlands are usually found on steeper gradients where water velocities are higher. The presence of an outflow (connection) will also improve the transport of sediments out of the wetland, minimizing the effectiveness of the wetland at trapping sediments.

Slope Unconnected - The probability that sediments will reach the wetland is Low because sediments will only reach the wetland by surface erosion from overland flows. These overland surface (sheet) flows tend to be low in volume because the catchment areas tend to be small. Most of the water in slope wetlands comes from groundwater seeps. The default for effectiveness is Moderate because, although slope wetlands are usually found on steeper gradients where water velocities are higher, the absence of an outflow (connection), will improve sediment trapping in the wetland if there is any vegetation present.

Lacustrine Fringe - The probability that sediments will reach the wetland is Low because sediments in streams and rivers will be deposited in the lake before they reach the wetland. There is little chance that sediments will reach a lakeshore wetland. The only case where there is a significant chance of sediments reaching a wetland is if the sediment source is adjacent to the wetland. The default for effectiveness is Moderate because sediments in lakeshore wetlands are subject to resuspension by storms. Although lakeshore wetlands tend to have a dense cover of vegetation, water velocities may be significant during storms, and these may resuspend and disperse any new sediment deposits.

Tidal Saltwater Fringe - The probability that sediments will reach estuarine fringe wetlands is High because these wetlands are directly connected to the rivers and coastal currents carrying the sediments. The tidal inundation of wetlands occurs twice daily, thus increasing the chance that sediment bearing waters will reach the wetland. The default for effectiveness is Moderate because the estuarine fringes in saltwater tend to be more exposed. Storms in these location will tend to resuspend sediments, thus decreasing the effectiveness of the sediment trapping that occurs in the wetland.

Tidal Freshwater Fringe - The probability that sediments will reach freshwater fringe wetlands is High because these wetlands are directly connected to rivers that transport sediments. The tidal inundation of wetlands occurs twice daily, thus increasing the chance that sediment bearing waters will reach the wetland. The default for effectiveness is also High because tidal freshwater fringe wetlands tend to be heavily vegetated and located in areas with very low water velocities. Much of the water fluctuation is vertical rather than horizontal.

Table G-12 summarizes the ratings for probability and effectiveness that are to be used in establishing level 1 vulnerability calls for HGM subclasses.

Table G-12. Level 1 Assessment: Ratings for Probability and Effectiveness of Sediment Retention

Wetland Hydrogeomorphic Subclass	Probability	Effectiveness
Riverine Flow-through	High	Moderate
Riverine Impounding	High	High
Depressional Flow-through	Low	Moderate
Depressional Closed	Low	High
Slope Connected	Low	Low
Slope Unconnected	Low	Moderate
Lacustrine Fringe	Low	Moderate
Tidal Saltwater Fringe	High	Moderate
Tidal Freshwater Fringe	High	High

Table G-13 displays the predicted vulnerability to sediments of wetlands in different hydrogeomorphic Subclasses for a Level 1 assessment based on Table G-12. The effectiveness of certain individual wetlands in trapping sediments may lead to calls other than those predicted by Table G-12. If a vulnerability call other than that predicted is made, the analysts should document the justification for this call.

Table G-13. Level 1 Assessment: Vulnerability Rating for Wetlands in Different Hydrogeomorphic Subclasses

High	Moderate	Low
Riverine Flow-through	Depressional Closed	Depressional Flow-through
Riverine Impounding		Slope Connected
Tidal Saltwater Fringe		Slope Unconnected
Tidal Freshwater Fringe		Lacustrine Fringe

If hydraulic connectivity of a wetland is affected by a road, the analyst will adjust the HGM class and vulnerability according to the situation.

Level 2 Assessment

For a Level 2 assessment, the general probability and effectiveness ratings used in the Level 1 assessment may be directly evaluated by the analyst for individual wetlands based on site specific characteristics.

For example, increased residence time generally results in more effective sediment removal. Water velocity decreases, and thus retention time increases, with decreasing slope. Therefore, riverine wetlands associated with lower stream gradients are more likely to perform sediment retention than those with steep gradients (Hupp, 1993).

To better understand stream power (transport capacity) and the routing capabilities of riverine wetlands present in the watershed, fieldwork with the stream channel analyst is recommended.

In addition, the effectiveness of individual wetlands in storing sediments may influence vulnerability calls derived from the Level 1 assessment.

Wetlands with constricted outlets are more likely to retain sediments than those with unconstricted outlets (Adamus, 1993). In addition to physical controls on wetlands outlets, beavers are also known to exert a widespread influence on the structure and dynamics of riverine valley connected wetlands

(Naiman et al. 1988). A beaver dam may force channel flow into adjacent wetlands during floods. Studies of beaver-influenced streams in Quebec, Canada, recorded up to 6500 m^3 of sediment stored per dam (Naiman et al., 1986).

Sediment deposition is also greatly enhanced by wetland vegetation, which creates frictional resistance to water movement (increasing residence time) and limits resuspension by wind mixing. Wetlands with mostly open water are less likely to retain sediments than those that are extensively vegetated. Wetlands with dense vegetation (low vegetation-open water interspersion) are more likely to retain sediments that those with sparse vegetation. Table G-14 provides a decision matrix for rating the effectiveness of sediment trapping in riverine wetlands (based on Adamus, 1993).

Table G-14. Rating the Effectiveness of Sediment Trapping

	Roughness		
	Vegetation Cover		
Water Velocity & Constriction	**>66%**	**33-66%**	**0-33%**
low gradient <1% and constricted outlet	High	High	High
low gradient and outlet >1/3 width	High	High	Moderate
moderate gradient 1-5% and constricted outlet	High	Moderate	Moderate
moderate gradient and outlet >1/3 width	Moderate	Low	Low
high gradient >5% and constricted outlet	Moderate	Low	Low
high gradient and outlet >1.3 width	Low	Low	Low

Record the vulnerability on the wetlands assessment worksheet (Form G-1). Vulnerability of wetlands to sedimentation should be identified on Map G-5.

Nutrient Assessment

Scientific Background

Nitrogen (N) and phosphorus (P) are two nutrients that stimulate plant growth. The balance between available nitrogen and phosphorus in solution in the water column determine the primary productivity of waterbodies. Forested mountain streams of the Pacific Northwest are generally very low in both nitrogen and phosphorus, and primary productivity is often naturally low.

Forest streams of the Northwest commonly have very low background concentrations of N compounds, often less than 0.01 mg/L (MacDonald et al., 1991). Nitrogen export varies significantly during the year, reaching annual maximums in autumn with leaf fall. The presence of nitrogen-fixing plants in the riparian forest such as alder can significantly increase levels of dissolved nitrogen (NO_3) in stream runoff (Binkley and Brown, 1993).

Phosphorus is very tightly conserved within forest ecosystems (Salminen and Beschta, 1991). Mass balance calculations of phosphorus from forested watersheds indicate that substantial amounts of phosphorus are adsorbed to and carried by sediment. Fine-grained sediments are most important in phosphorus sorption due to their high proportion of surface area to volume (Meyer, 1979; Holton et al., 1988). The net effect of phosphorus sorption by stream sediments is to convert dissolved phosphorus to fine particulate phosphorus which is suspended during periods of high, turbulent flows. The majority of this phosphorus is contained within the mineral lattice of the sediment and is therefore unavailable for solution or biological uptake. Furthermore, sediment transport primarily occurs in the winter months, having a reduced significance for summertime phosphorus concentrations. However, the dynamics of phosphorus and sediment in stream systems of the Northwest have received relatively little attention (Salminen and Beschta, 1991).

In a review of 40 studies which collected phosphorus data, Salminen and Beschta (1991) report that background concentrations of total phosphorus for streams draining forested watersheds in the Northwest averaged 0.034 mg/L (range 0.005 to 0.090 mg/L) and mean concentrations of orthophosphorus averaged 0.012 mg/L (0.003 to 0.026 mg/L). The range of nitrogen and phosphorous concentrations is shown in Figure G-7.

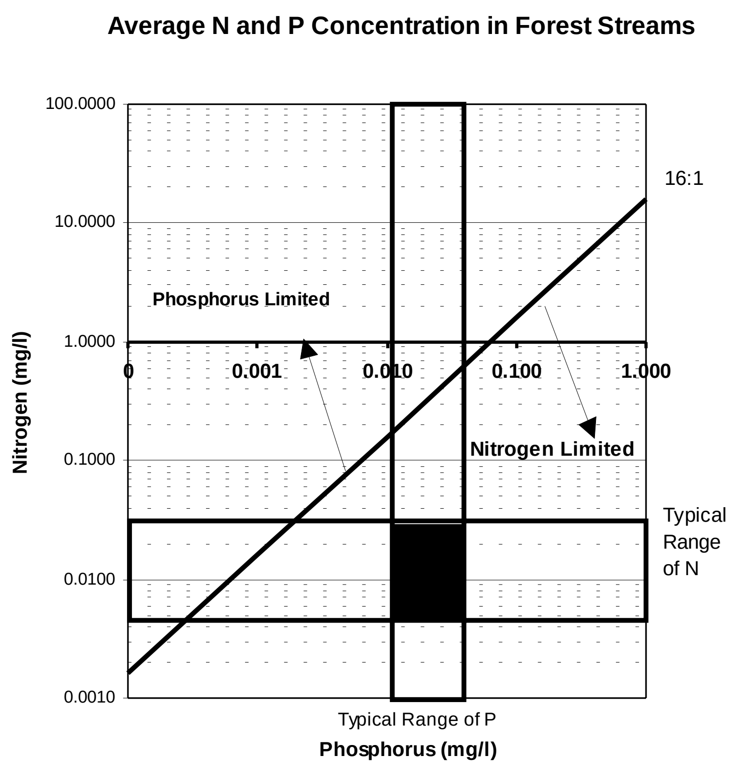
Generally, the greater the concentration of growth nutrients, the greater the aquatic primary production. However, a critical atomic ratio of 16:1 nitrogen to phosphorus (approximately 7:1 mass ratio) can be used to estimate the nutrient limiting aquatic plant growth. If the ratio is less than 16:1 then nitrogen is considered the limiting nutrient. If the ratio is greater than 16:1, then P is considered limiting (MacDonald et al., 1991). The 16:1 line is shown on Figure G-7. This relationship implies that if a waterbody is nitrogen-limited, then an increase in phosphorus will not increase primary production. Similarly, if the waterbody is phosphorus-limited, an increase in nitrogen will not affect it. In either case, the limiting nutrient deficit must be eliminated before aquatic production can increase.

The typical range of nitrogen and phosphorous concentrations observed in Pacific Northwest forest streams is shown on Figure G-7. It is evident that most are likely to be both low in primary productivity and nitrogen-limited.

Cutting of forests has been shown to increase NO_3 as much as 3-5 times for a relatively short-lived period following harvest (3-5 years) (Fredricksen et al., 1975; Sollins and McCorison, 1981), although severe burning has resulted in changes as much as 10 times higher. Numerous studies have shown that the absolute amount of nitrogen which enters a stream is still relatively small and that the risks of nitrate pollution from forest practices are low (Bisson et al., 1992; Fredricksen et al., 1975). Indeed, small additions of N or P to aquatic systems of the Northwest can often have beneficial effects enhancing primary and secondary productivity (Bisson et al., 1992; MacDonald et al., 1991). Fertilization is a possible source of short-term effects on nitrogen.

Soil erosion and input of organic matter are the primary mechanisms for increasing P levels in aquatic systems (MacDonald, 1991). Literature reviews concluded that forest practices in the Pacific Northwest are unlikely to substantially increase phosphate concentrations in aquatic systems (MacDonald et al., 1991; Salminen and Beschta, 1991; Wolf, 1992). Phosphorus is rarely applied as fertilizer in the Northwest because it is seldom considered to be limiting to forest growth (Gessel et al., 1979). The low nitrogen-phosphorus ratio in most forest stream systems suggests that changes in phosphorus loading with sedimentation are unlikely to have adverse effects on the aquatic productivity.

Figure G-7. Typical range of nitrogen and phosphorus concentrations among forest streams of the Pacific Northwest



Receiving waterbodies such as lakes and reservoirs serve as nutrient "sinks" and may accumulate nutrients. Often lakes have higher primary productivity, and may be more sensitive to nutrient loading from natural processes and forest practices than streams draining to them. Eutrophication is a condition in which the rate of primary productivity creates high levels of aquatic plant biomass leading to increases of aquatic fauna (secondary productivity) and changes in dissolved oxygen and pH. Phosphorus retention by lakes is dependent on lake volume, shape, and phosphorus inputs (Larsen and Mercier, 1976) and detention times. Birch et al., (1980) concluded that phosphorus increases from land use in watersheds draining to Lake Washington increased primary productivity of the lake. Lakes act as phosphorus traps, causing downstream decreases in expected phosphorus loads (Dillon and Kirchner, 1975).

It is common to classify lakes by trophic status encompassing a range of productivity from very low (oligotrophic) to very high (hypereutrophic) (Table G-15). Some lakes are particularly vulnerable to elevated inputs of nutrients which can eutrophy a mesotrophic lake or exacerbate an already eutrophied lake condition. Excessive aquatic plant growth and nuisance algae can subsequently create diurnal fluctuations in dissolved oxygen and pH, and deplete dissolved oxygen when plants die. These conditions can lead to problems with fish and the aesthetics, odor, and taste of water. Lake basin morphology is an important factor controlling nutrient flux and trophic status. Wide, shallow, and warm lakes with long detention times favor plant growth (G. Ice, NCASI, 1994, pers. comm.).

Table G-15. General Trophic Classification of Lakes and Reservoirs in Relation to Phosphorus, Nitrogen, Secchi Transparency, and Chlorophyll *a* (annual means and ranges)
Table modified from Vollenweider (1979).

	Trophic Levels			
Parameter	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hypereutrophic**
Total Phosphorus Range (mg m^{-3})	8.0 (3.0-17.7)	26.7 (10.9-95.6)	84.4 (16-386)	-- (750-1200)
Total Nitrogen Range (mg m^{-3})	661 (307-1630)	753 (361-1387)	1875 (393-6100)	– –
Secchi Transparency Depth (m)	9.9 (5.4-28.3)	4.2 (1.5-8.1)	2.45 (0.8-7.0)	-- (0.4-0.5)
Chlorophyll *a* (mg m^{-3})	1.7 (0.3-4.5) <4ug/L*	4.7 (3-11) 4-10ug/L*	14.3 (3-78) >10ug/L*	-- --

*data from Welch (1980)

Oligotrophic = low nutrients and relatively stable dissolved oxygen concentrations (near saturation), favoring aquatic fauna over flora.

Mesotrophic = intermediate between the two.

Eutrophic = high nutrients and fluctuating dissolved oxygen concentrations with period of relatively low concentrations, favoring aquatic flora over fauna.

No explicit numeric criterion currently exists for nutrients in the state water quality standards (although these are being developed in the current triennial review of the water quality standards). Nevertheless, the vulnerability of waterbodies to increased nutrient loading resulting from forest practices is assessed relative to the propensity for nuisance aquatic growth. The vulnerability criterion used in this assessment is that the relative contribution of nutrients from forest practices shall not be routed to eutrophic lakes so as to prevent recovery or worsen the growth of vegetation; or the relative contribution of nutrients from forest practices shall not be routed to a mesotrophic lake which could elevate the trophic status to eutrophic. Streams are not considered vulnerable to changes in nutrient loading unless a receiving waterbody such as a lake or estuary is vulnerable. Wetlands, by definition, are naturally high in organic matter and nutrients, and small changes from forest practices do not harm essential wetland processes. Therefore, wetlands are not considered vulnerable to changes in nutrient loading with forest practices and are not assessed.

Nutrient Assessment Procedure

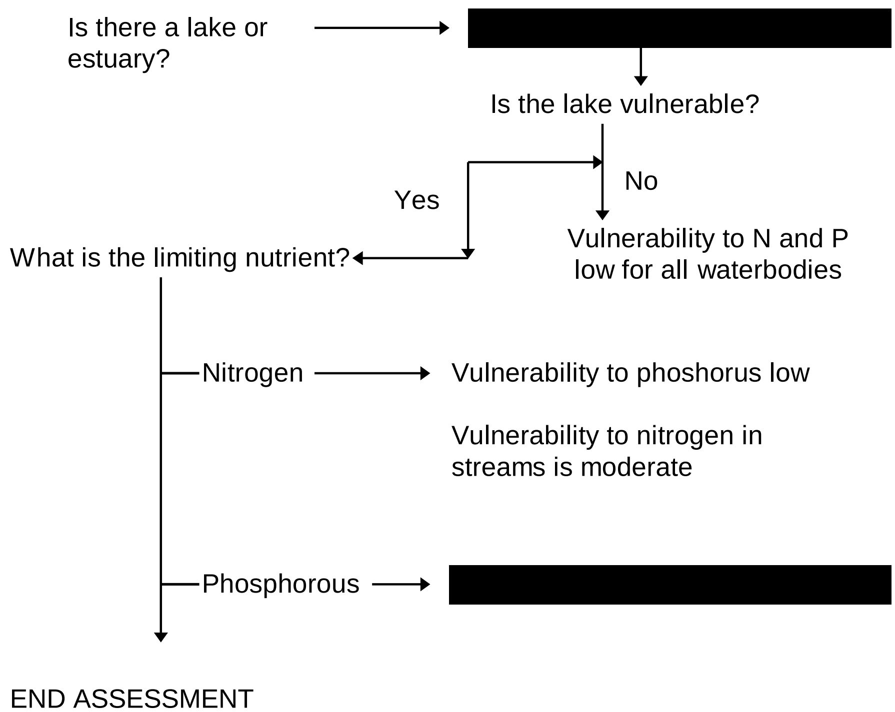
The first step of the assessment is to determine the trophic status of lakes and estuaries. If eutrophication exists, the limiting nutrient is identified and contributing streams are assessed for vulnerability to change in that parameter. If no vulnerability to lakes or estuaries is identified, then streams are not further assessed.

Lake Nutrient Vulnerability

The first step of the assessment is to determine the primary productivity status of lakes, and if present, estuaries and nearshore marine waters. The analyst determines the trophic status of lakes by considering their ability to retain nutrients, and their current condition.

Trophic Status. The water quality characteristics, productivity status, and land use effects of many lakes in the state have been studied by the DOE. The analyst should seek such information if it exists. The DOE 305(b) list is a source of information from some states. Scientific studies that support

Figure G-8. Nutrient assessment flow chart.



DOE listings may be available. Reports may provide a determination of productivity status, or data that can be compared to Table G-15 to establish whether the lake is oligotrophic, mesotrophic, or eutrophic.

In the absence of data, the analyst can estimate the productivity status using observation of aquatic plants within the lake. Generally, aerial photographs available via DNR will be of low reliability for observing submerged aquatic plants or algae blooms. Usually aquatic plants establish in the shallower portions of the lake. As deposition of sediment and organic matter from dying vegetation shallows the lake along the edges, the plant growth grows increasingly towards the deeper areas. The area of vegetation growth relative to surface area of the lake suggests the productivity status. A lake with little aquatic vegetation or algae along the edges is likely oligotrophic. Eutrophic lakes typically exhibit relatively high plant biomass and are often dominated by very few plant species. Recent summer aerial photographs can be used to evaluate whether portions of the lake are occupied by aquatic vegetation or algal blooms.

Vulnerability of lakes to nutrients depends on lake size relative to nutrient loading and detention time. Mean depth is regarded as the best single index of detention time and shows a general inverse correlation to productivity at all trophic levels among large lakes (Neumann, 1959). Therefore, the analyst can assess vulnerability using the mean depth and trophic state Table G-16.

Table G-16. Vulnerability Call for Adverse Levels of Limiting Nutrients in Lakes.

	Mean Lake Depth		
Trophic Status	**Deep (>50 feet)**	**Medium (20-50 feet)**	**Shallow (<20 feet)**
Oligotrophic	Low	Low	High
Mesotrophic	Moderate	Moderate	High
Eutrophic	Moderate	High	High

If the lake receives either a moderate or high vulnerability determination, the analyst determines the likely limiting nutrient.

Limiting Nutrient. We recognize that because of the complex functional interactions in lake ecosystems, the limiting factor concept needs to be applied with caution (Stumm and Morgan 1981). The evolution of appropriate nutrient ratios in fresh waters involves a complex series of interrelated biological, geological, and physical processes, including photosynthesis, the selection of species of algae that can fix atmospheric nitrogen, alkalinity, nutrient supplies and concentrations, rates of water renewal, and turbulence. It is beyond the scope of Watershed Analysis to adequately characterize lake or estuary nutrient dynamics and trophic response to nutrient loading. However, the concept applies to be consistent with the simplifications necessary to determine the likely response of lakes to forest practices.

We use the nitrogen and phosphorus ratio to establish whether nitrogen or phosphorous may be limiting phytoplankton. Based on steady state stoichiometry (Stumm and Morgan 1981). Lakes with N:P ratio greater than 16 are phosphorous limited, and less than 16 are nitrogen limited. If nutrient concentration data is available, the ratio can be calculated directly and should be used. In the absence of lake specific nutrient data, the analyst can assume that waterbodies in volcanic geology are nitrogen limited, and waterbodies in glacial and granitic geologies are phosphorus limited (Gregory et al., 1987; Thut and Haydu, 1971).

Stream Nutrient Vulnerability Assessment

The analyst will then evaluate the vulnerability of streams draining to the lake to determine whether forest practices are likely to cause adverse changes in nutrient loading.

Nitrogen

In nitrogen limited systems, concentrations of less than 0.3 mg/L nitrate-N will prevent eutrophication (Brooks et al., 1991; Cline 1973). Vulnerability is provided in Table G-17.

Table G-17. Vulnerability of water bodies to nitrate-N

Average Annual Concentration (mg/L)	Vulnerability
<.050	Low
0.05-0.10	Medium
0.1-0.3	High

Since the average nitrate-N concentration of forest streams is generally far below this level, the assumed vulnerability of streams is low and no assessment is required. There is no recommended method for estimating the concentration of nitrate-N in forest streams. If the analyst can determine the nitrate concentration, the vulnerability determination should reflect the above criteria.

Waterbodies determined to have moderate or high vulnerability to nitrate should be identified on Map G-6 (nutrient vulnerability map).

Phosphorus

To prevent eutrophication, the annual yield as indexed by the average annual concentration of total phosphates should not exceed 0.10 mg/L in streams (MacKenthun, 1973) or 0.05 mg/L in streams flowing to lakes and reservoirs (MacDonald et al., 1991).

The vulnerability of lakes to phosphorus from forest practices is driven by the mechanism of phosphorus bound to sediment. Vulnerability to phosphorus is determined based on sediment yield. The analyst should consult with the surface erosion analyst who develops an estimate of background sediment yield for sub-basins within the WAU.

Phosphorus yield has been approximated by multiplying suspended sediment yield by 0.001 (i.e., 0.1% phosphorus content) (Ahl, 1988). Though Ahl (1988) investigated streams primarily in Scandinavia, Salminen and Beschta (1991) indicated that this may represent a reasonable approximation of phosphorus composition based on a broad range of rock type data (Table G-18).

Table G-18. Phosphorus composition of rock types
(from Salminen and Beschta, 1991)

Rock Type	Phosphorus Composition (%)
Sedimentary	
Limestone	0.020[1]
Sandstones	0.040[1]
Shales	0.080[1]
Red Clay	0.140[1]
Sedimentary-mixed (mean)	0.070[1]
Igneous	
Rhyolite	0.055[1]
Granite	0.087[1]
Andesite	0.123[1]
Syenite	0.133[1]
Monzonite	0.139[1]
Diorite and Dacite	0.144[1]
Gabbro	0.170[1]
Basalt	0.244[1]
Igneous rock	0.118[2]
Igneous-plutonic (mean)	0.134[3]
Igneous-volcanic (mean)	0.141[3]

[1] Phosphorus composition values from Omernik (1977)
[2] Mean of the values given by Goldschmidt (1958) and Van Wazer (1961)
[3] Mean of plutonic or volcanic types listed above

a. Determine P content of geology. Based on the dominant rock type of the WAU, the analyst should determine the specific phosphorus composition from Table G-18.

b. Calculate background P yield. Using the estimated background fine sediment for the lake basin obtained from the surface erosion and mass wasting modules, assume that the fine sediment yield is suspended and multiply by the phosphorus concentration to approximate the total phosphorus yield (metric tonnes) to the lake.

Sediment Yield (tonnes/km2) x Area (km2) x P Content (%) = P Yield (tonnes) (10)

c. **Calculate mean annual runoff.** The analyst may use basin-specific gauge data, if available, or estimate the runoff based on records from an appropriate USGS station. The annual volume of runoff is reported by the USGS for water survey stations.

   Report the total runoff in cubic meters of water.

d. **Calculate background average phosphorus concentration input to the lake.** Take approximated background phosphorus yield (tonnes) and divide by average annual runoff to yield the average P concentration (mg/L)

$$\text{Background P conc. (mg/L)} = \frac{\text{background P yield (tonnes)} \times 10^6}{\text{average annual runoff (m}^3\text{)}} \qquad (7)$$

Make this calculation for each sub-basin within the watershed, and calculate an area-weighted mean annual P concentration.

Low vulnerability if estimated background P concentration is less than 0.025 mg/L.

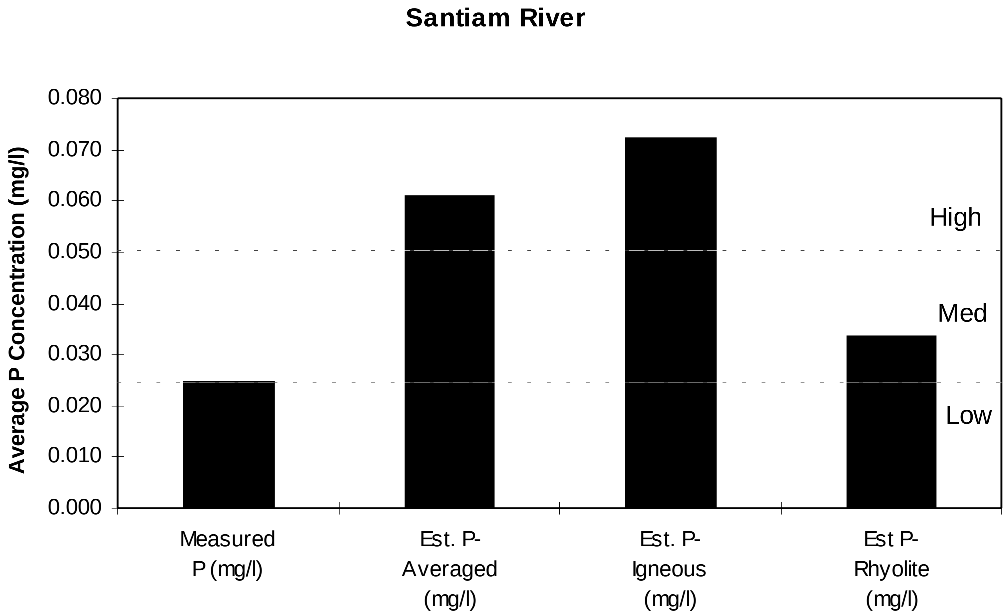
Moderate vulnerability if estimated background P concentration is greater than 0.025 mg/L but less than 0.05 mg/L.

High vulnerability if estimated background P concentration is greater than 0.05 mg/L.

The above calculation was performed for the M. Santiam River in Oregon where phosphorous and sediment concentration has been measured for a number of years. Figure G-9 shows results of the above model computation compared with measured phosphorus yield.

Figure G-9. An example of the phosphorous concentration calculation for the M. Santiam River, Oregon, where phosphorous, sediment, and flow have been measured for several years.

Modeled values using various geologic rock types are compared to measured values. Geology in the watershed is mixed.



The dominant rock type in the M. Santiam River basin is tuffaceous igneous and andesite. While the rhyolite estimate matches measured phosphorous reasonably well, assumptions associated with other rock types are sufficiently high that moderate or high vulnerability would have been identified where a low vulnerability exists. Therefore, while this analysis appears to provide a reasonable first order estimate of phosphorus yield based on geology, analysts must use caution in extrapolating the phosphorus content of surface materials.

Waterbodies determined to have moderate or high vulnerability to phosphorus should be identified on Map G-6 (Nutrient Vulnerability Map).

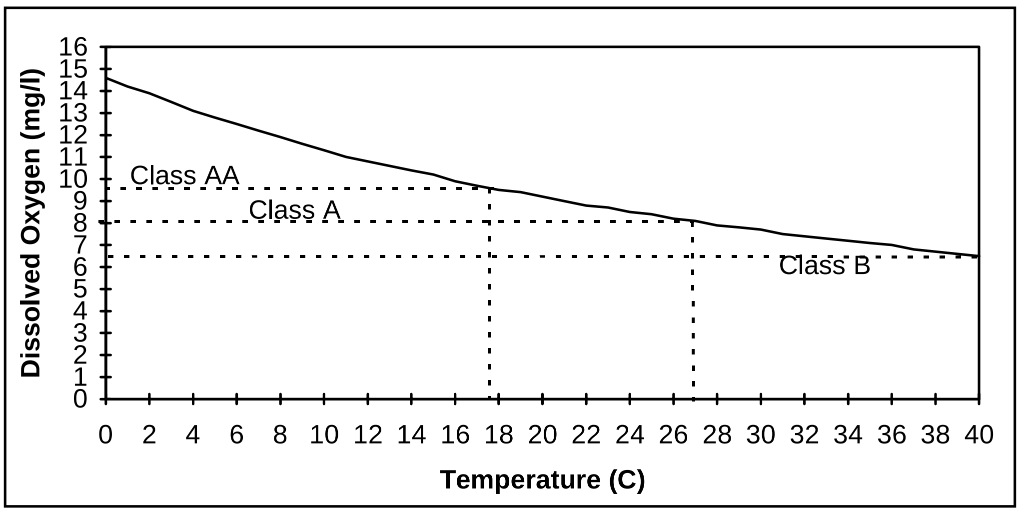
Dissolved Oxygen Assessment

Scientific Background

In general, most forest streams exhibit cool temperatures, rapid aeration rates, and relatively low biochemical oxygen demand (BOD). This typically allows streams to be at or close to saturation for dissolved oxygen (DO) (MacDonald et al., 1991), especially at the relatively high velocities and turbulence characteristic of streams in forested watersheds of the Northwest. By definition, wetlands include anoxic conditions and DO is naturally low.

Introduction of fine particulate organic matter to waterbodies can increase BOD and decrease DO. High background organic loading can naturally occur with soils rich in organic matter or be affected by forest management where loading of slash into streams has been extreme. This situation can further be exacerbated by high water temperatures (Figure G-10). A study in a Canadian forest stream found that fresh slash loaded to impound a low gradient (<1%) stream coupled with a low reaeration rate caused DO to drop to zero (Plamondon et al., 1982). The concentration of dissolved oxygen in water at saturation decreases with increasing temperature and can approach, if not exceed, the numeric criteria when ambient conditions are very warm (Figure G-10). Temperature is also important because it affects the rate at which organic matter is oxidized. Low DO may occur at any time of the year, but is most likely to occur during the warmest weather and lowest flows.

Figure G-10. Relationship of dissolved oxygen saturation (mg/L) in water to temperature (°C) at sea level assuming no reaeration



Streams are considered vulnerable to dissolved oxygen (DO) if forest practices cause the dissolved oxygen concentration to fall below the state water quality criteria provided in Table G-19.

Table G-19. Dissolved Oxygen Water Quality Standards

Class AA Waters	9.5 mg/L
Class A Waters	8.0 mg/L
Class B Waters	6.5 mg/L

One of the primary factors influencing the DO of streams is the reaeration rate which is determined by the velocity and turbulence of water as it flows through the system. Most forest streams have sufficient velocity and bed roughness that turbulence is more than sufficient to maintain a high concentration of DO in the water column, even under low summer flows and normal organic loading.

Ice (1991) developed an equation to calculate reaeration based on reach-averaged stream characteristics:

$$K_2 = \frac{37 * W^{2/3} * S^{1/2} * g^{1/2} * Vmax^{7/8}}{Q^{2/3}} \qquad (8)$$

where:
W = active stream width (ft)
S = slope (ft/ft)
g = gravitational constant (32.2 ft/s^2)
Vmax = maximum velocity (ft/s)
Q = stream discharge (cfs)

where the aeration rate is adjusted for stream temperatures different than 20° C:

$$K_{2adj} = K_2 * (1.024)^{T-20} \qquad (9)$$

Streams are vulnerable to lowered DO when the reaeration rate coefficient (K2) is less than 10 day^{-1} (at 20°C). Note that the lower the water temperature, the lower the reaeration coefficient. Streams with reaeration rate coefficients greater than 10 day^{-1} can accept a high amount of BOD without significant oxygen depletion.

Most forest streams have low vulnerability to low DO because fine organic debris is generally low, and reaeration of flowing water is more than sufficient to maintain high levels of DO. Only streams with low reaeration rate coefficients will be vulnerable to markedly lowered DO. Most forest streams have high reaeration rates when calculated using the above equation. An example calculation is made using average data measured during the summer for the variables in the reaeration equation (reported in Sullivan et al., 1990). For example, at a distance 10 km (6 miles) downstream from watershed divide, the values of input parameters are:

Example Reaeration Calculation

Width (w)	= 13.12 ft	(4 m)
Velocity (v)	= 0.66 ft/s	(0.2 m/s)
Discharge (Q)	= 7 cfs	(0.2 cms)
Slope (S)	= 3%	

Substituting into the equation and solving:

K2 = 38.4 Adjusting for Temperature at 16.$^{3°}$ C (61 F) : $\mathbf{K_{2adj} = 35.2}$

This value is well above the threshold necessary for reaeration.

Current forest practices are not generally believed to input sufficiently large enough amounts of slash to cause management-induced depletion of DO through increases in BOD, except where DO is naturally low (Skaugset and Ice, 1989). Adverse depletion of DO, however, may occur when the following conditions are present (MacDonald et al., 1991; Ice, 1992; Ice, 1991):

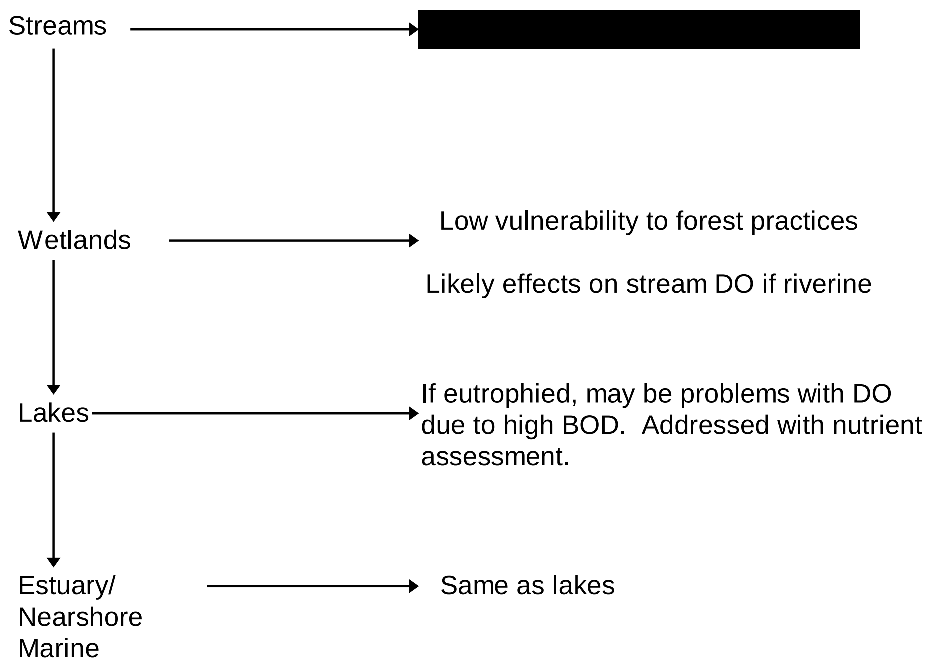
- Very slow-moving, low gradient, warm streams with low discharge (i.e., low reaeration rates), including impounded wetlands, especially those formed by beaver; or
- Heavy inputs of fine organic debris to low-flow streams causing a large BOD, or naturally high concentrations of organics; or
- Warm, eutrophic waterbodies where high rates of photosynthesis and respiration cause diurnal fluctuations in DO (consuming O_2 without re-aeration). These conditions often accompany lake eutrophication; therefore nutrient analysis will suffice for lakes.

Dissolved Oxygen (DO) Assessment Procedure

The dissolved oxygen assessment involves screening the watershed for the presence of situations where streams are very slow-moving, loaded with organic matter, and potentially of high temperature (Figure G-11). Wetlands are assumed to have low DO since they often meet these criteria, even when contributing streams do not. In fact, wetlands are assumed to have a significant effect on DO for some distance downstream from a wetland outlet and may be a source of DO problems to aquatic life in streams. DO in lakes and estuaries and near-shore marine environments is assumed to be controlled by biological and physical processes within them, and are beyond the scope of this assessment. The DO of these waterbodies are assumed to have low vulnerability to forest practices.

The analyst will look for situations where streams are slow-moving, relatively deeper and low turbulence.

Figure G-11. Dissolved Oxygen Assessment Flow Chart



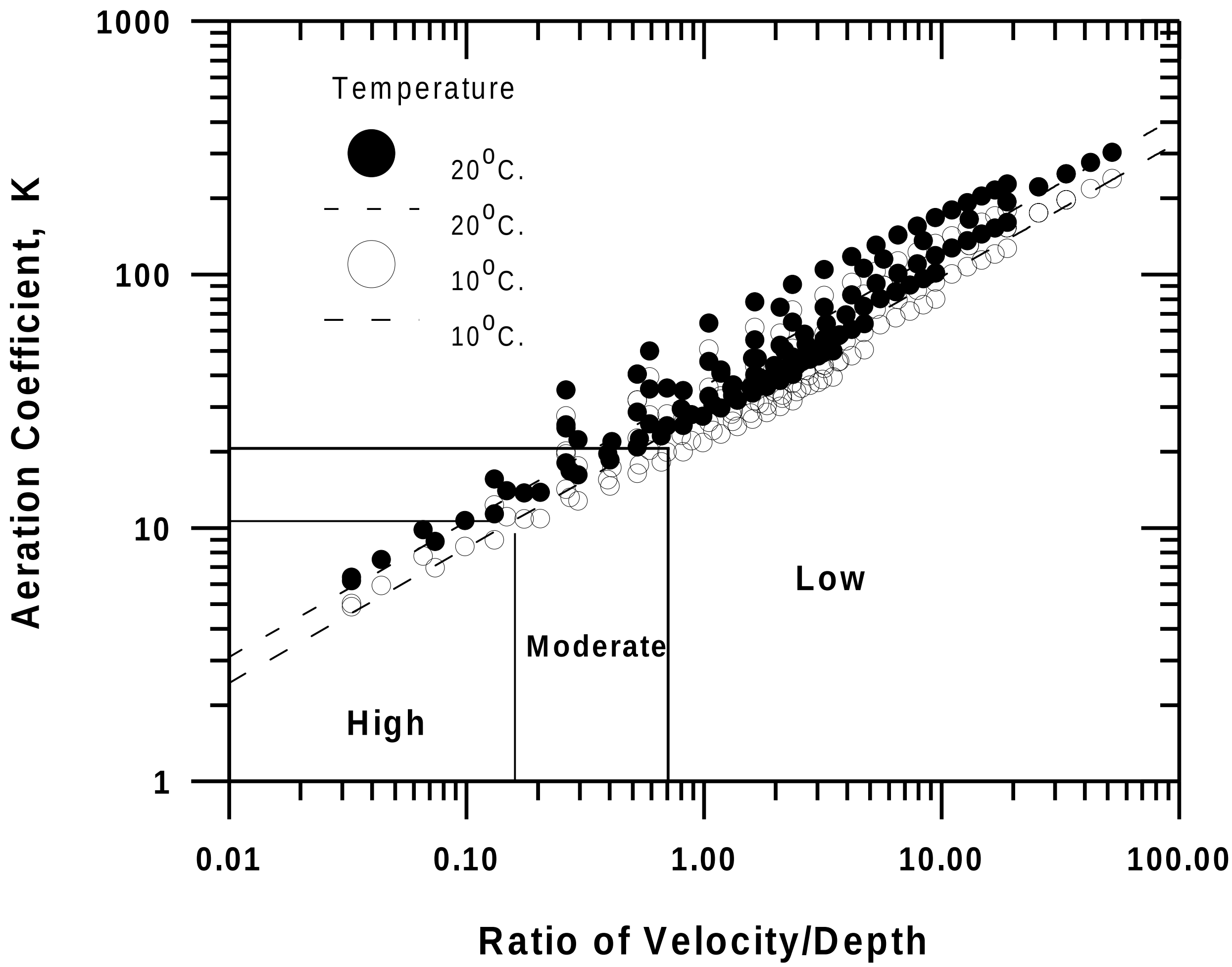
To simplify use of the reaeration equation (eq 8) for purposes of watershed analysis, we sought to determine flow conditions with low reaeration coefficients ($k<10$). To do so, solved eq 12 for a number of different combinations of the stream parameters (Q,v, w, s) to determine the factors to which reaeration are most sensitive. Although depth is not included in the equation, its influence can also be determined using the relationship:

$$Q = v \times d \times w$$

where Q is discharge, v is velocity, d is depth and w is width.

The reaeration coefficient is proportional to velocity and inversely proportional to depth. It is relatively insensitive to width. These relationships suggested a relationship between K and the ratio of v/d. We found that the ratio v/d was closely related to K over a wide range of values for parameters in equation 12 (Figure G-12.) Note that K approximately 20% lower when water temperature is 10º C compared to 20º C. Thus, the v/d ratio is a good indicator of reaeration coefficient K. Vulnerability to DO is shown on Figure G-12 where thresholds of K are 10 for high vulnerability and 20 for moderate vulnerability. (Vulnerability is based on the cooler temperature, since this value is more conservative, and the objective of management is to minimize temperature. However, the analyst may adjust the v/d ratio for appropriate temperature using equation 12 directly.

Figure G-12. Vulnerability of streams to low dissolved oxygen based on calculations of the reaeration coefficient (k) in relation to the ratio of velocity to depth

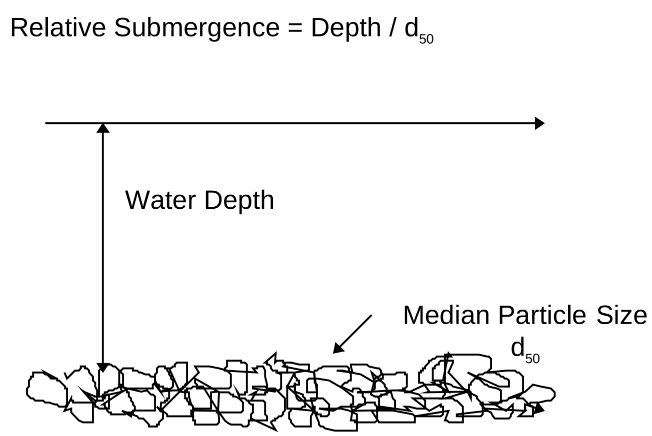


The threshold for **HIGH** vulnerability (K<10) occurs at v/d equal to 0.18. The threshold for MODERATE vulnerability (10<K<20) occurs at v/d equal to 0.7. For example, assuming average reach velocity of 25 cm/s, the average reach depth would need to be more than 140 cm for low reaeration and 36 cm for moderate reaeration. Low reaeration is usually associated with streams that are slower and deeper than most forest streams and this situation is not expected to occur frequently.

The analyst determines where very slow-moving, low gradient, warm streams with low discharge are located in the watershed, and whether fine organic debris has been loaded to these areas. Utilize the stream channel segment map produced in the Channel Module (Map E-1) for locations of all low discharge streams with less than 1% gradient. Low gradient streams are most likely to be sufficiently slow and deep to meet the above criteria. Stream segments associated with extensive riverine impounded wetlands should be included as these are likely to be the most likely situations naturally experiencing low DO due to low v/d ratios and high organic loading. In most forested watersheds, if a stream demonstrates any signs of turbulence (i.e., rippling of water surface to produce other than tranquil flow) it is probably well-aerated. To apply the relationships, both velocity and depth should be averaged over substantially long reach (>30 channel widths), and should be based on summer streamflow conditions.

Level 2 Assessment. In addition to the v/d relationship, high bed roughness can improve aeration by inducing turbulent mixing. To account for bed roughness that induces turbulence, the analyst calculates the relative submergence of the streambed, calculated as the ratio of the water depth relative to the average particle size of the streambed material (Figure G-13).

Figure G-13. Relative Submergence = Water Depth (mm) / Avg. Particle Size (mm)



(Consult the channel analyst for methods to determine the bed particle size).

Note: If a stream is greater than 1% and has any degree of turbulence, it is well above the critical reaeration rate coefficient. In contrast, very slow moving, low gradient streams may require calculation of the reaeration rate coefficient using equation 12.

The analyst will visit some stream segments to determine whether depth and velocity criteria are met. If segments are riverine wetlands, they may assume that velocity and depth criteria for vulnerability threshold are met.

Pay particular attention to identified stream reaches which may experience high temperatures exceeding the criteria, such as low elevation and/or low riparian shade. Temperature measurements may be helpful to determine this, but locations where riparian shade is below target are identified on the Riparian Shade Situation Map (Map D-4).

Vulnerability Determination

Situations of low reaeration coefficient are likely to occur where the velocity/depth ratio is low and relative submergence is high. The analyst shall make the vulnerability call, according to Table G-20. Values of relative submergence greater than 10, coupled with velocity and depth combinations in Figure G-12 are conditions leading to high vulnerability of the stream to low levels of DO.

Table G-20. Vulnerability Criteria for Dissolved Oxygen

	Relative Submergence		
Vel-Depth Call	<3	3-10	>10
High	Mod	High	High
Medium	Low	Mod	Mod
Low	Low	Low	Low

Vulnerability can be increased if high organic loading exists. In addition, existing conditions of high water temperature may also increase the vulnerability identified in Table G-20, although this effect can be accounted for using the appropriate Figure G-12.

Level 2 DO Stream Assessment Procedure

The analyst may improve upon the estimate of reaeration coefficient by obtaining field measured data and solving equation 12 for each reach of interest. The vulnerability criteria are the same as for the standard assessment.

Lakes, Wetlands, and Estuaries

Lakes and estuaries may be vulnerable to adverse levels of DO resulting from runoff into lakes with poor reaeration rates, especially lakes that are thermally stratified during portions of the year. Low DO in lakes would likely be a secondary effect of eutrophication resulting from nutrient loading. The vulnerability of lakes to nutrients is assessed above, and therefore DO will not be addressed directly.

Wetlands are likely to have low dissolved oxygen because of their high organic content, low velocities and deeper depths. However, forest practices are not likely to affect already low values and the dissolved oxygen of wetlands is considered to have low vulnerability to forest practices.

Waterbodies determined to have moderate or high vulnerability to Dissolved oxygen should be identified on Map G-7 (DO/pH vulnerability map).

Acidity and Alkalinity

Scientific Background

Generally pH is within 6.5 to 8.5, although watershed conditions may create some conditions that are naturally more acidic or alkaline than these conditions. For example, soils very high in organic content may have low pH, while very basic lithologies may produce soils with high alkalinity. Few studies have rigorously assessed the ability of forest practices to change water pH, but available data indicate that pH is not generally affected by forest practices (MacDonald et al., 1991). In many cases, the buffering capacity of the soil precludes forest practices from affecting stream pH (Stottlemeyer, 1987).

Streams are considered vulnerable to acidity or alkalinity if pH falls outside the range of the following state water quality criteria listed in Table G-21.

Table G-21. Water quality standards for pH

Class AA Waters	6.5 to 8.5 (±<0.2 units)
Class A and B Waters	6.5 to 8.5 (±<0.5 units)

All streams and waterbodies are assumed to have low vulnerability to pH. The presence of indicators sensitive to pH should trigger a Level 2 assessment to determine the source of pH and management effects.

One situation where pH may be naturally low is where streams are very rich in dissolved organic matter. This condition may occur on some soil types, and it can often be the case if there are wetlands or bogs as a source of stream water. The analyst should examine soil information for situations of high organic content, notably organically rich soils. Though not affected by forest practices, this condition could be important to fish habitat quality. The water quality analyst should inform the fish habitat analyst that low pH conditions may exist.

Waterbodies determined to have moderate or high vulnerability to pH should be identified on Map G-7 (DO/pH vulnerability map).

Use of Existing Water Quality Data

Although water quality vulnerability to forest practices is determined primarily by assessing potential based on watershed conditions, measured water quality data can be very helpful in determining whether hypothesized vulnerabilities are correct. If forest management “stressors” are present, that is, if past practices are already likely to have influenced a water quality parameter, data from the area can help the analyst evaluate the vulnerability determinations. Table G-22 helps to explain the likely situations that will occur when measured data is compared to modeled vulnerability.

Table G-22. Modifying vulnerability determinations based on available water quality data

		Observed Water Quality Parameter	
		Does Exceed	**Does Not Exceed**
Predicted Vulnerability	**Moderate or Low** (parameter within standard and not likely to exceed)	**Change to vulnerability to HIGH**	**CORRECT**
	High (parameter likely to exceed standard)	**CORRECT**	**Change vulnerability to MODERATE**

Several situations are possible. If vulnerability determinations match measured data results, then the module results would appear to be appropriate. If the measured data does not match the vulnerability determinations, than the vulnerability determinations should be changed to reflect the measured data according to Table G-22. When vulnerability determinations are changed, the rationale for doing so and an explanation for the deviation should be included in the module report.

A number of factors should be included in the analyst’s vulnerability assessment due to current condition before over-riding the vulnerability determinations developed in previous sections.

1. Are the type of forest practices present and of sufficient spatial effect to have affected water quality?

2. Are current water quality conditions a result of a legacy of past forest practices that are no longer in effect?

3. Are current water quality conditions a result of natural disturbances? If so, what is the link between the disturbance and water quality that caused exceedances?

4. Are other landuses affecting the water quality conditions?

After consideration of disturbance, forest practices and watershed factors, the analyst will change the vulnerability determinations as appropriate. The analyst will include a discussion of measured vs. modeled water quality and discuss disturbance and watershed factors that may have caused error in vulnerability determination from module criteria.

Finally, precise location of boundaries between waterbodies likely to be within standards and those exceeding cannot be guaranteed with the general methods provided in this module. For example, the location where predicted temperature changes from 16ºC to 17ºC will appear more exact on maps than the method is likely to be able to predict accurately but the boundary between the two has significant regulatory significance. Furthermore, there is likely to be some error in predicting maximum temperature with the temperature screen due to the range of annual variability in water temperature due to climatic influences (Sullivan et al., 1990). When measured data indicates water quality criteria are exceeded vulnerability should be adjusted. However, conclusions regarding the utility of the water quality module methods in predicting the direction and magnitude of change with forest practices can be aided by discussion of model performance relative to criteria in a spatial and temporal context.

Water Quality Assessment Report

The Water Quality Assessment Report organizes and presents results of the water quality assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. The report should describe the results of the analysis and any conclusions reached relative to the critical questions. While the Water Quality Assessment Report should be concise, it should be complete enough so that, together with the other module products, it provides the input necessary for the synthesis and prescription phases of Watershed Analysis where the information developed in the analysis modules is incorporated into land use decision-making.

The assessment report should include the following:

- Documentation of all information used in the assessment of conditions of waterbodies within the WAU. This includes aerial photos, maps, anecdotal information, and any other information used to characterize riparian conditions.

- A summary of the assessment results and vulnerability determinations for each water quality parameter.
- A description of any deviations from the standard methods and why the changes were necessary.
- A description of any additional analyses that were performed.
- A discussion of the analyst's confidence in the work products. Consider factors such as the amount, type, and quality of available information, extent of field data collection and observation, experience of the analyst, complexity of the terrain, availability and quality of aerial photographs and maps, and multiple lines of evidence for inferred changes.
- Answers to the critical questions presented at the beginning of the section. While it is not necessary to include this as a separate section, be sure that the critical questions are addressed somewhere in the report.

Maps

G-1 Waterbody map

G-2 Land use map

G-3 Reference temperature map

G-4 Temperature vulnerability Map

G-5 Sediment vulnerability map (if necessary)

G-65 Nutrient vulnerability map (if necessary)

G-7 DO and pH vulnerability (if necessary)

Summary Data

G-1 Wetlands assessment worksheet

G-2 Waterbody vulnerability determination worksheet

G-3 Temperature vulnerability worksheet

Water Quality Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Water body map (map G-1)
- Land use map (map G-2)
- Reference temperature map (map G-3)
- Temperature vulnerability map (map G-4)
- Sediment vulnerability map (map G-5), if map is necessary
- Nutrient vulnerability map (map G-6), if map is necessary
- DO and pH vulnerability (map G-7), if map is necessary

IV. **Summary Data**
- Wetlands assessment worksheet (form G-1)
- Water body vulnerability determination worksheet (form G-2)
- Temperature vulnerability worksheet (form G-3)

V. **Summary Text**
- Summary of assessment results and vulnerability determinations for each water-quality parameter
- Summary of all information used to document water-body conditions
- Description of any additional analyses that were performed
- Study methods, including description of sampling methods
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Recommendations for Level 2 (at Level 1 only)
- Does module report address all critical questions?

VI. **Other Information (optional)**
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Module Project Management

The module project management checklist is provided to assist the module leader and team members to schedule tasks and review interim and final module products. It is not a requirement of watershed analysis.

Table G-23. Water quality project task checklist

Project Tasks	Schedule	Review	Complete
Assemble start-up materials (e.g., mylar base map with WAU boundary and DNR hydro layer; soil survey, NWI maps, topo maps, aerial photos, 303(d) list, 305(b) report, available data)			
Start-up meeting—brief WQ team on process and intent. Schedule project tasks.			
Identify and map all waterbodies on mylar overlay (**Map G-1**): streams, lakes, wetlands, water supplies, and nearshore marine/estuarine waters. Notify other analysts where waterbodies are so they can include in assessments.			
Develop **Land Use Map (Map G-2)**.			
Query ps/ws, surface erosion, and channel erosion module leaders for key information. Query outside data sources.			
Conduct Vulnerability Assessment. Produce worksheet and map products.			
Team meeting to review results and interpretations.			
Produce module assessment report.			

Information Provided to Other Analysts by Water Quality Analyst

After completion of the water quality assessment the analyst is prepared to participate in Synthesis with an understanding of the vulnerability of water quality in the waterbodies in the WAU and has identified input variables likely to require consideration in prescriptions. In the case of temperature and sediment there is abundant information on these input variables generated in other modules. The analyst may alert the riparian, surface erosion and mass wasting analysts of the vulnerability and location of specific waterbodies and water supplies if location specific analyses will be advisable. If nutrient vulnerability is identified, the analyst should alert the surface erosion analyst so that phosphorous input from soil erosion can be more carefully evaluated. If dissolved oxygen is found to be vulnerable, the water quality analyst should alert the fish habitat analyst since this information may be important in understanding aquatic habitat effects on fish, and the channel and riparian analysts so that they can identify the locations and sources of organic matter loading.

Acknowledgments

This module represents the work of many people over the course of many years. This version was written by Kate Sullivan, Jerry Gorsline, Karen Walters, Doug Rushton and Dave Parks. Previous versions of the module were written by Hans Ehlert, Steve Toth, Dave Parks and Fred Greef. Significant technical comments were provided by Iris Goodwin, Walt Megahan, George Ice, Jim Ryan, Jeff Light, Rob Plotnikoff, Jim Matthews, Ed Rashin, Ron Figlar-Barnes, Fran Wilshusen, Bruce Cleland, Dave Ragsdale, Sally Marquis, Mark Hunter, Curt Veldhuisen, Sandra Donnelly, Jerry Erickson and Lee Benda. Important policy input was provided by Marcy Golde, Julie Thompson, David Roberts, Dick Wallace, Stephen Bernath and Chris Kelly. Judith Holter and Nancy Charbonneau assisted in preparing the final version for the Forest Practices Board.

This version of the Water Quality Module was accepted as part of the Forest Practices Board Manual by the Forest Practices Board on March 25, 1997 and became effective June 20, 1997.

The current module represents a work in progress. Further revision of the manual and methods are required to maintain the technical viability and credibility of the water quality assessment procedure. Periodic revision and incorporation of new methods will be needed.

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Appendix to

Water Quality Module